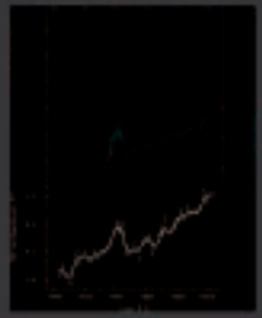
New insights into Antarctic climate change from a joint observational and modeling approach

David P. Schneider







National Center for Atmospheric Research, Boulder, CO

Jet Propulsion Laboratory, June 22nd, 2009

Acknowledgements

Eric Steig, University of Washington

Caspar Ammann, Bette Otto-Bliesner, NCAR

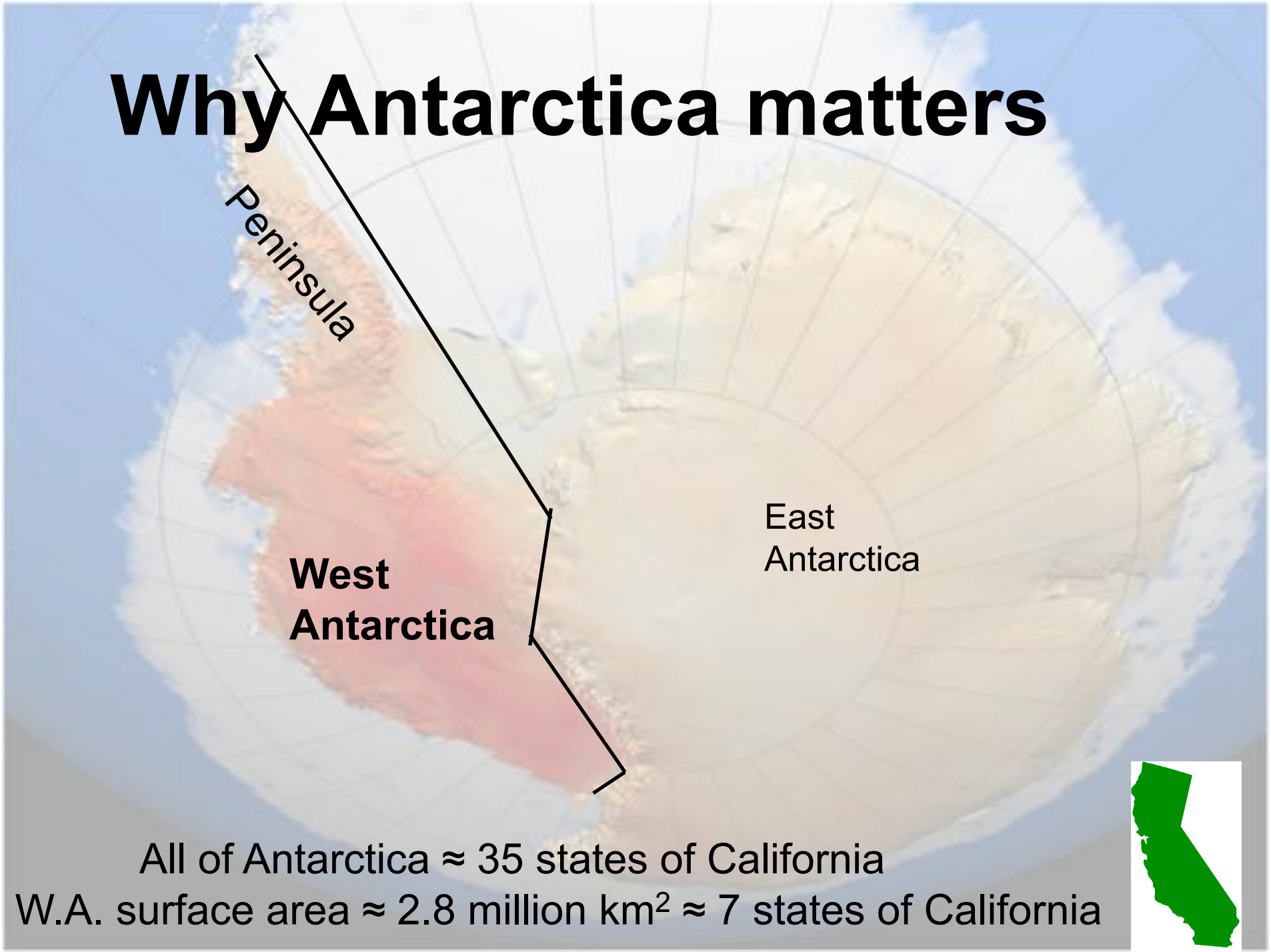
David Noone, University of Colorado

Clara Deser, NCAR

Outline

1) Introduction
2) Back 200 years
   Schneider et al. 2006, *GRL*
3) West Antarctica, 20th Century
   Schneider and Steig 2008, *PNAS*
4) The last 50 years in detail
   Steig, Schneider et al. 2009, *Nature*
5) What models say
   in progress
6) Summary

Why Antarctica matters



All of Antarctica ≈ 35 states of California

W.A. surface area ≈ 2.8 million km^2 ≈ 7 states of California

Why Antarctica matters

W.A. ice volume ≈ 2.5 million km^3 water ≈ enough to fill Great Lakes > 80 times

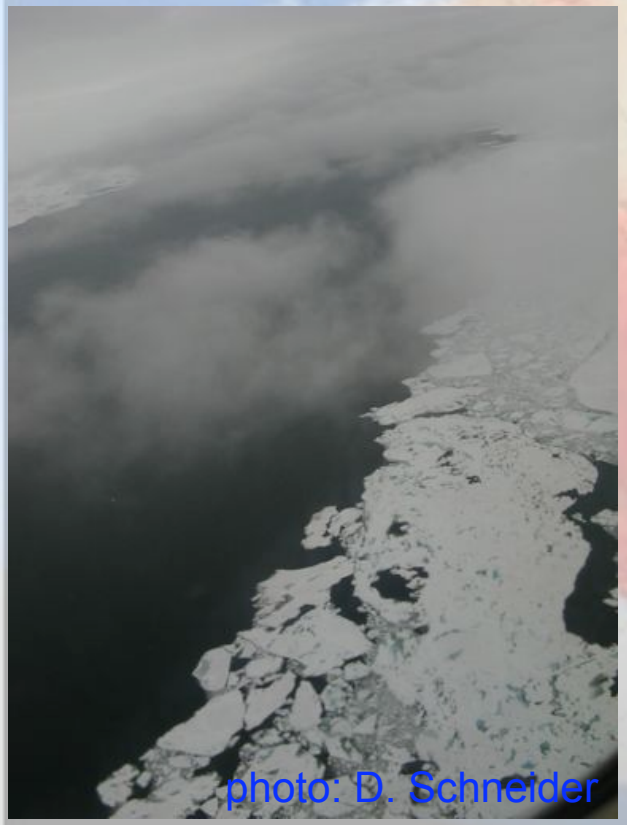


photo: D. Schneider

photo: NSIDC

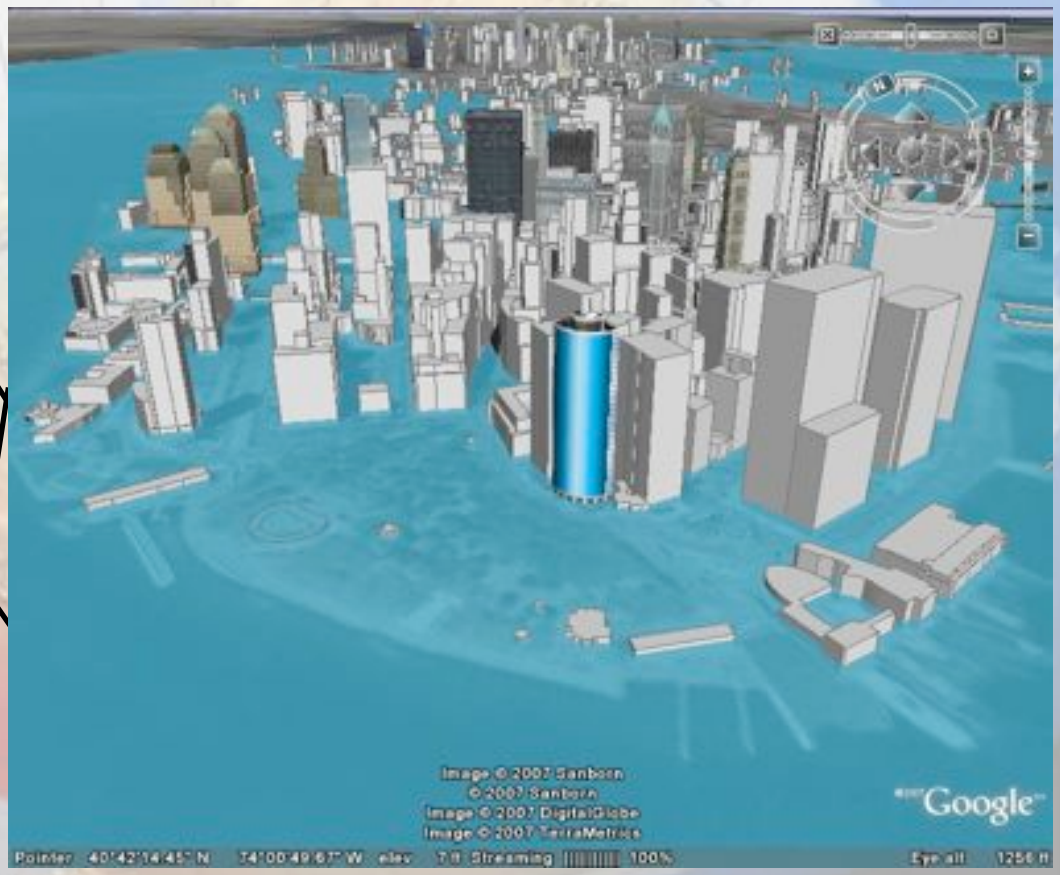
Background image: NASA

Why W. Antarctica matters

Enough to raise global sea level ~ 5 meters***

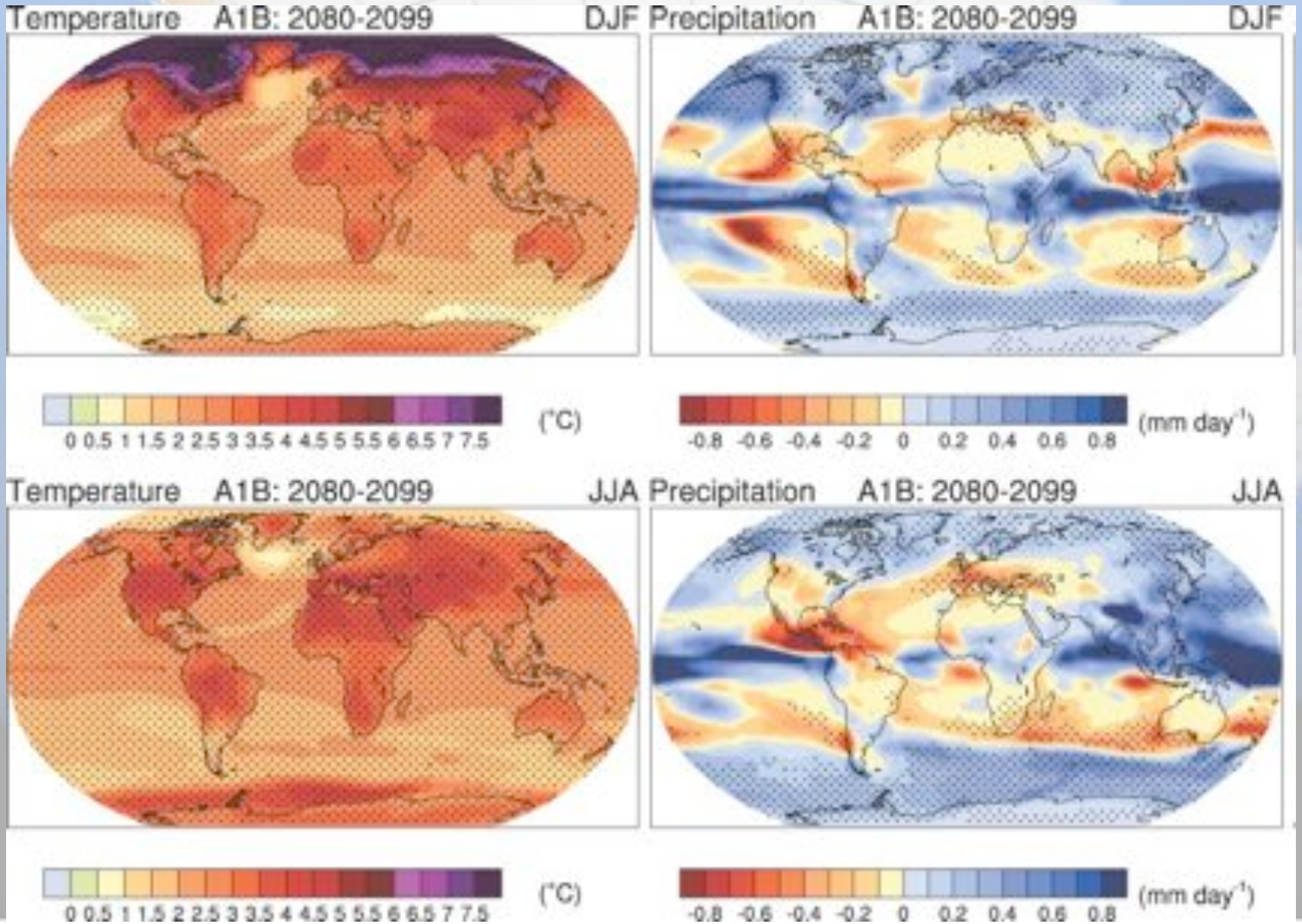
***portion that is vulnerable (Bamber et al. (2009)): 3.3 m

Northeast with + 6 m



Manhattan with + 8 m

Future Antarctic climate



Why Antarctica matters

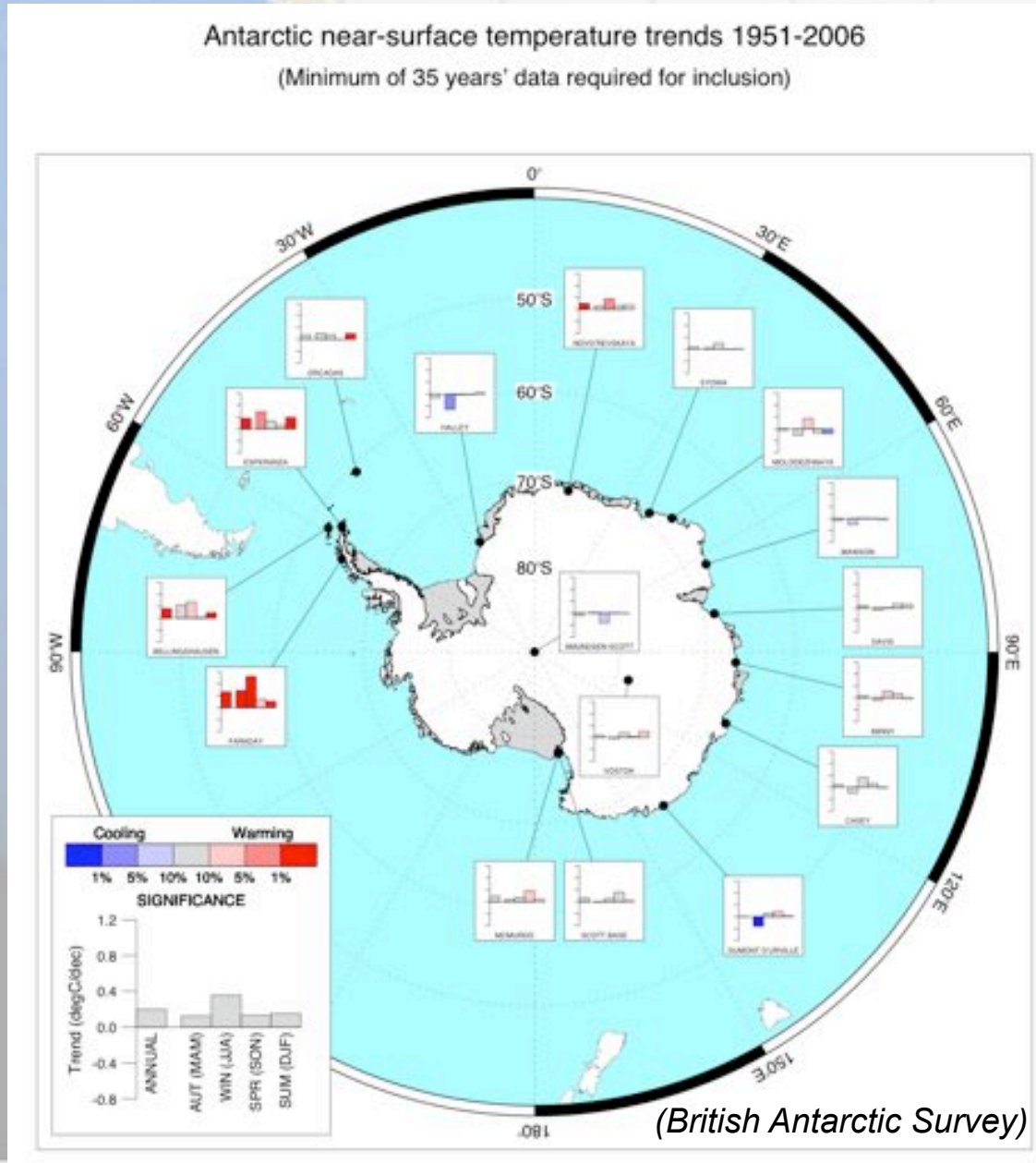
Will the ice sheet grow as more snow falls on it?

If Antarctic temperature rises 3°C by 2100,
more snowfall could offset sea level rise about 0.1 m

(Monaghan, Bromwich, Schneider, 2007)

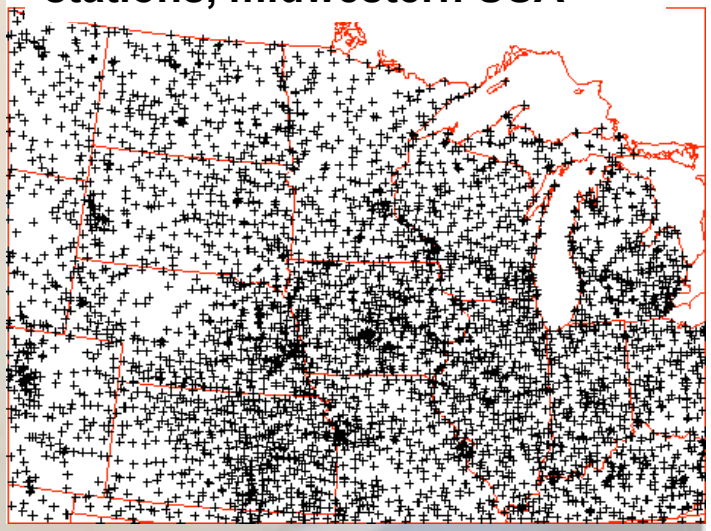
[that's less than the 20th-Century rise of about 0.2 m]

Signs of climate change



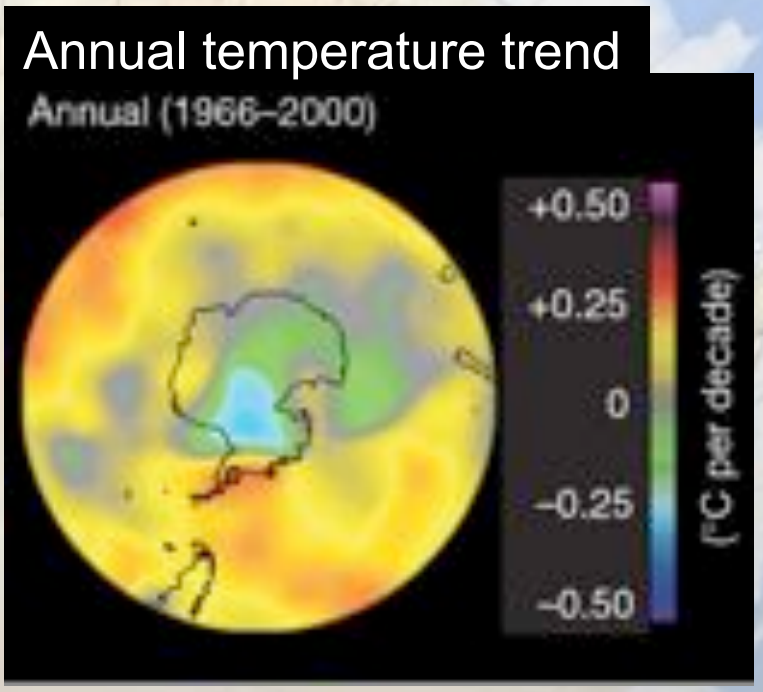
(British Antarctic Survey)

NOAA cooperative weather stations, midwestern USA



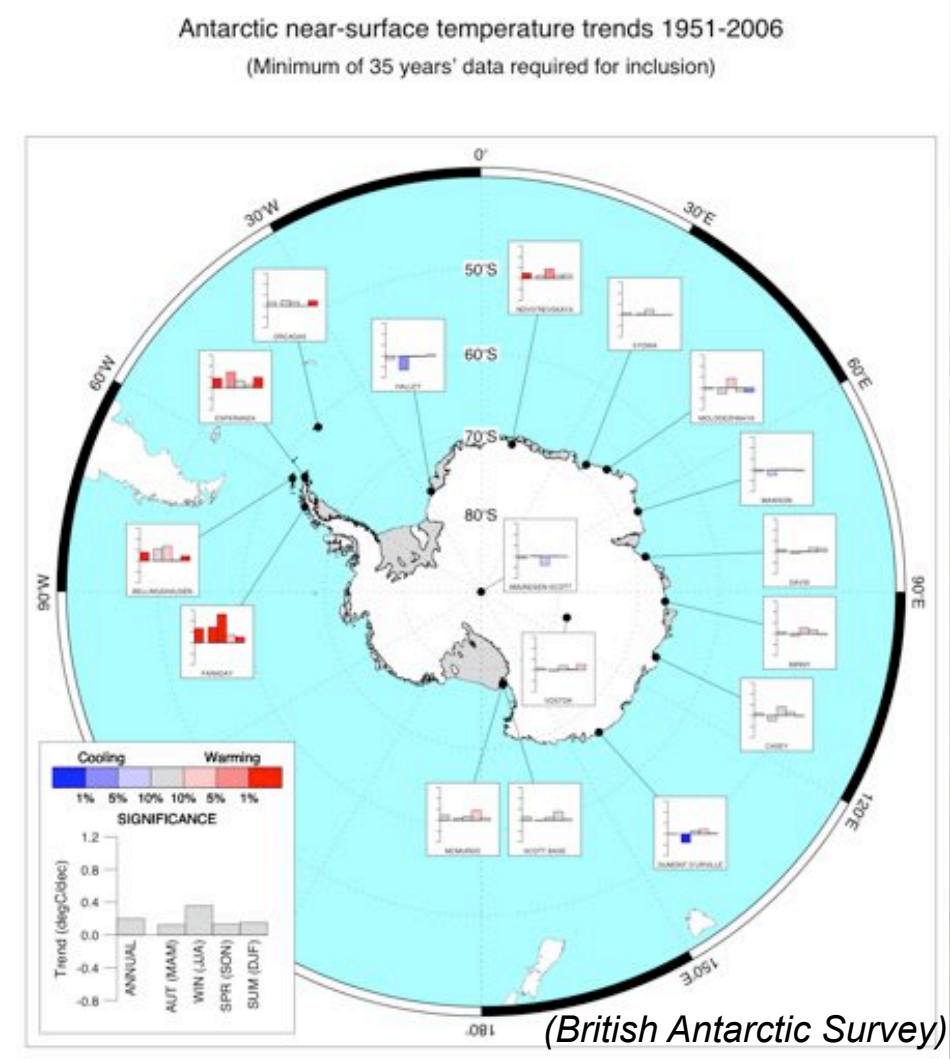
(NCAR)

Is Antarctica cooling?



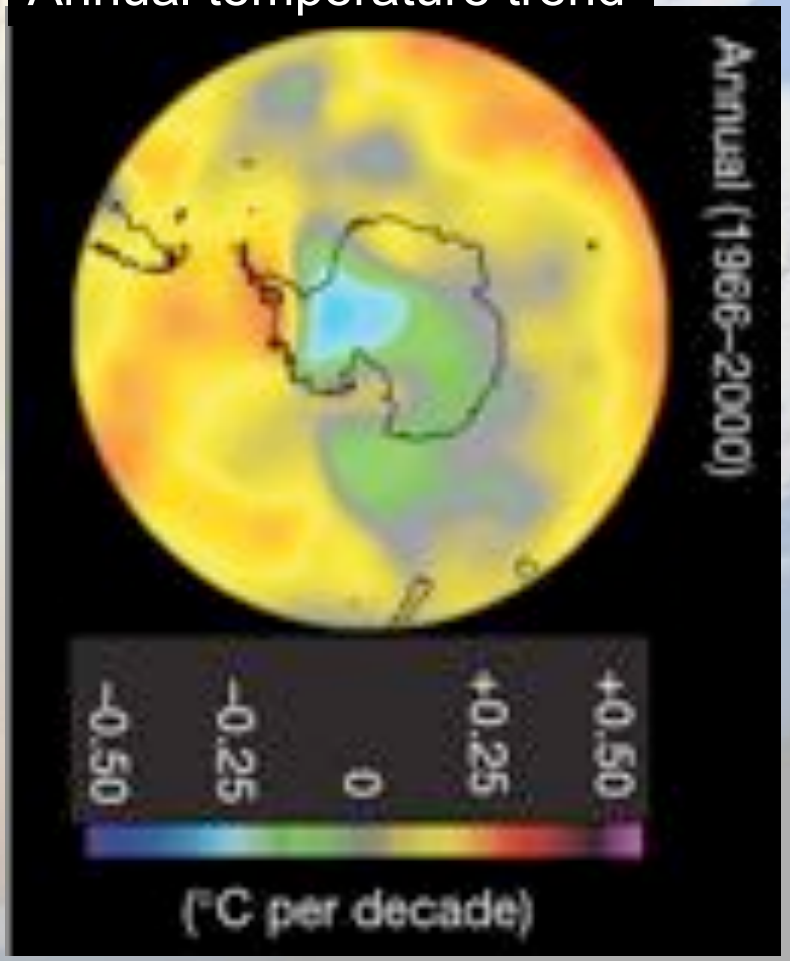
Doran et al., 2002

Is Antarctica cooling?



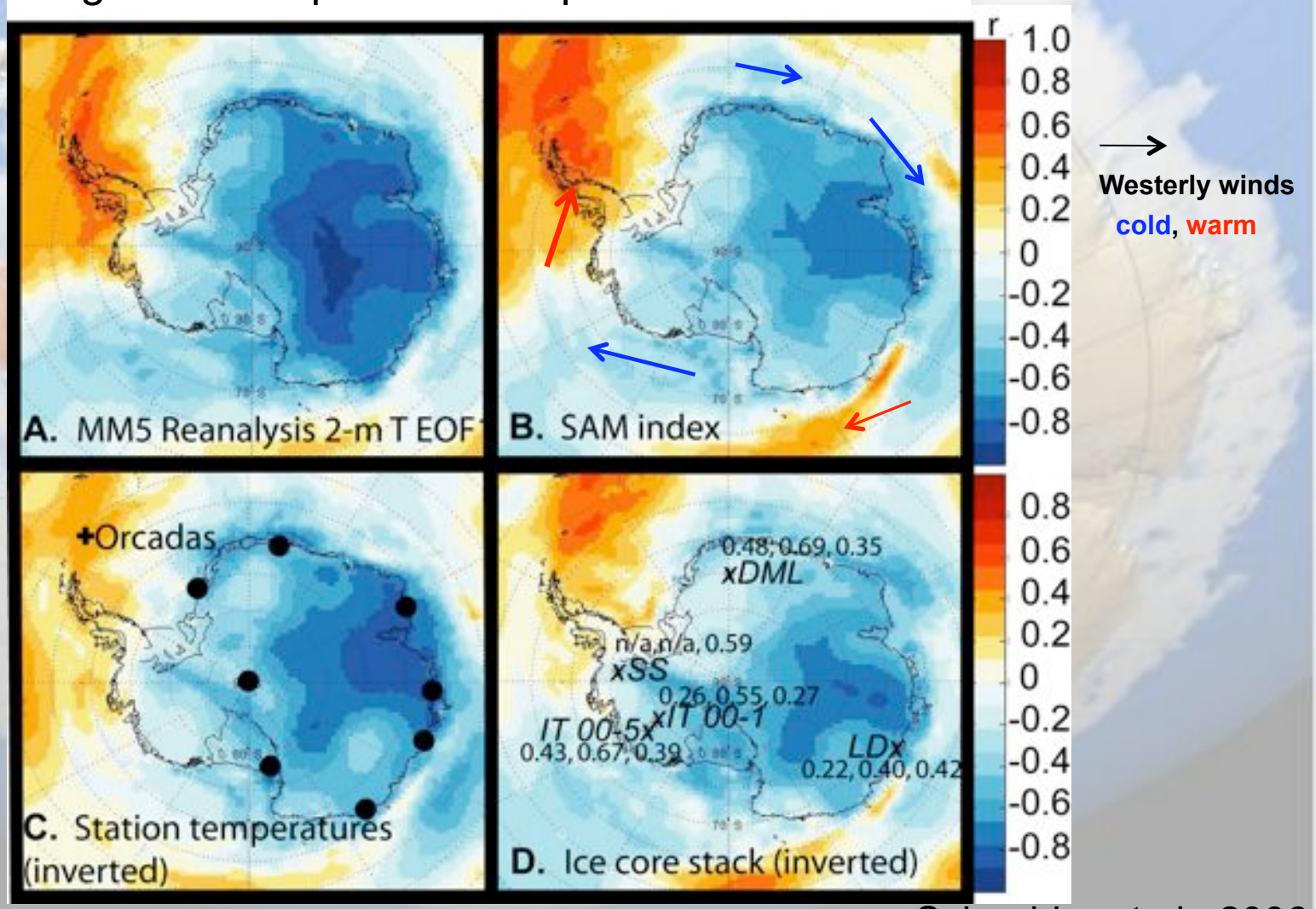
(British Antarctic Survey)

Annual temperature trend



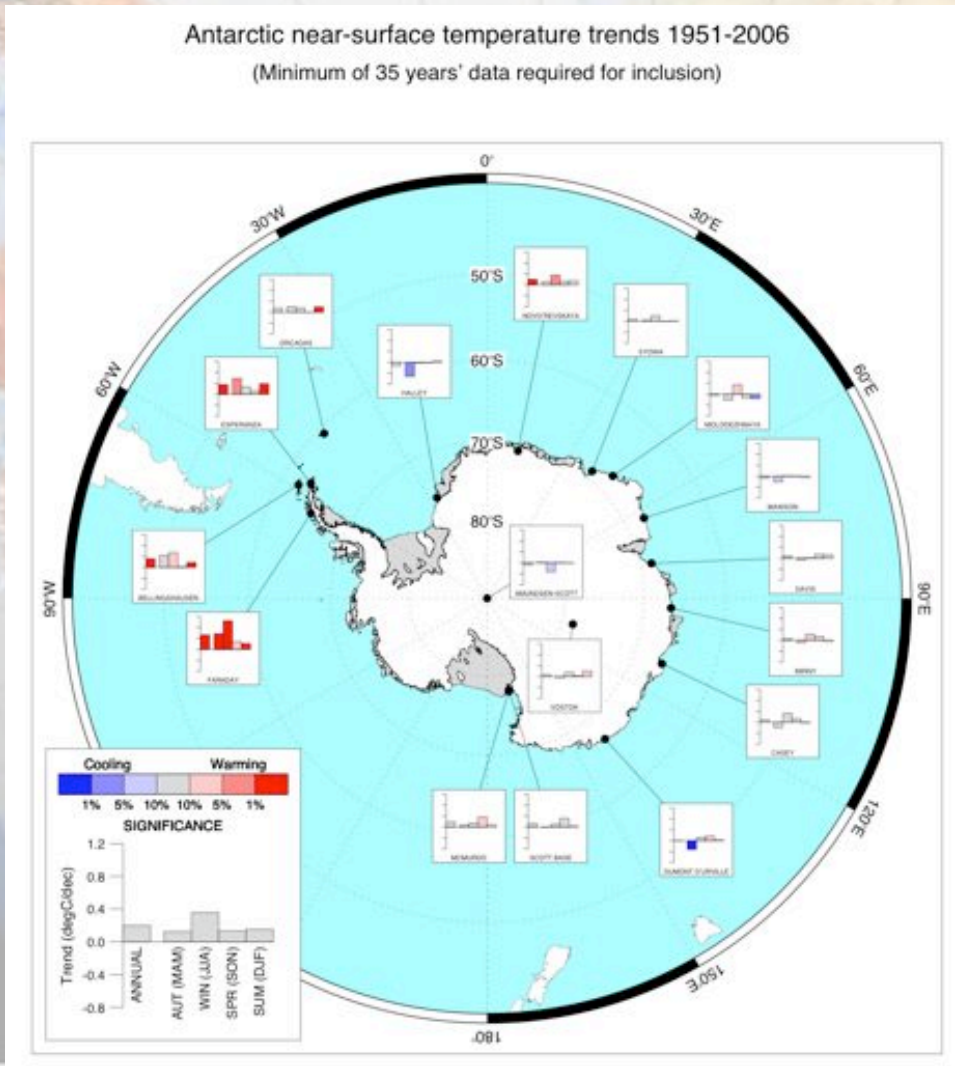
‘Cold continent-warm Peninsula’ pattern of variability

Regressions upon 2 m temperature anomalies



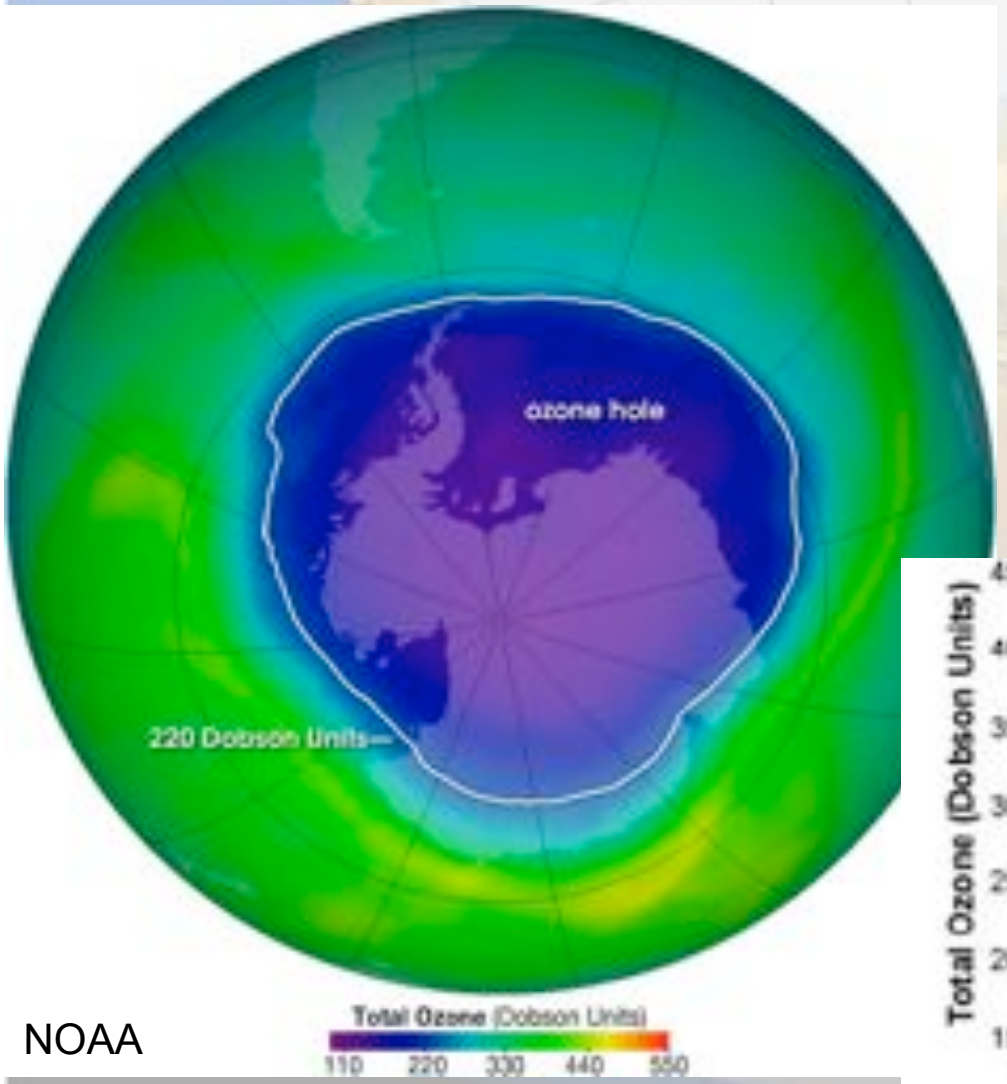
Schneider et al., 2006

‘Cold continent-warm Peninsula’ pattern of variability : Are trends of surface temperature an expression of this pattern?



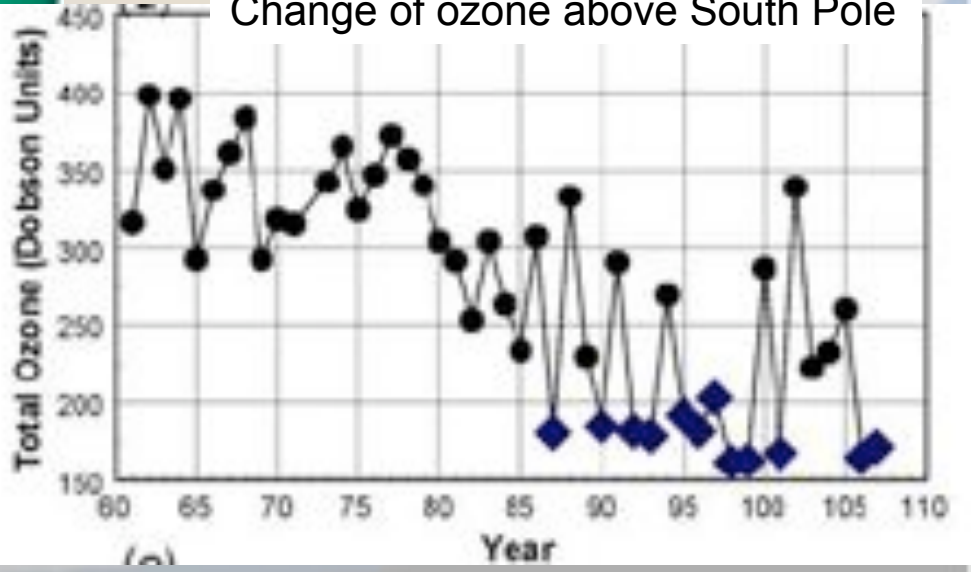
The Antarctic ozone hole

occurs 12-24 km above sea level



NOAA

Change of ozone above South Pole

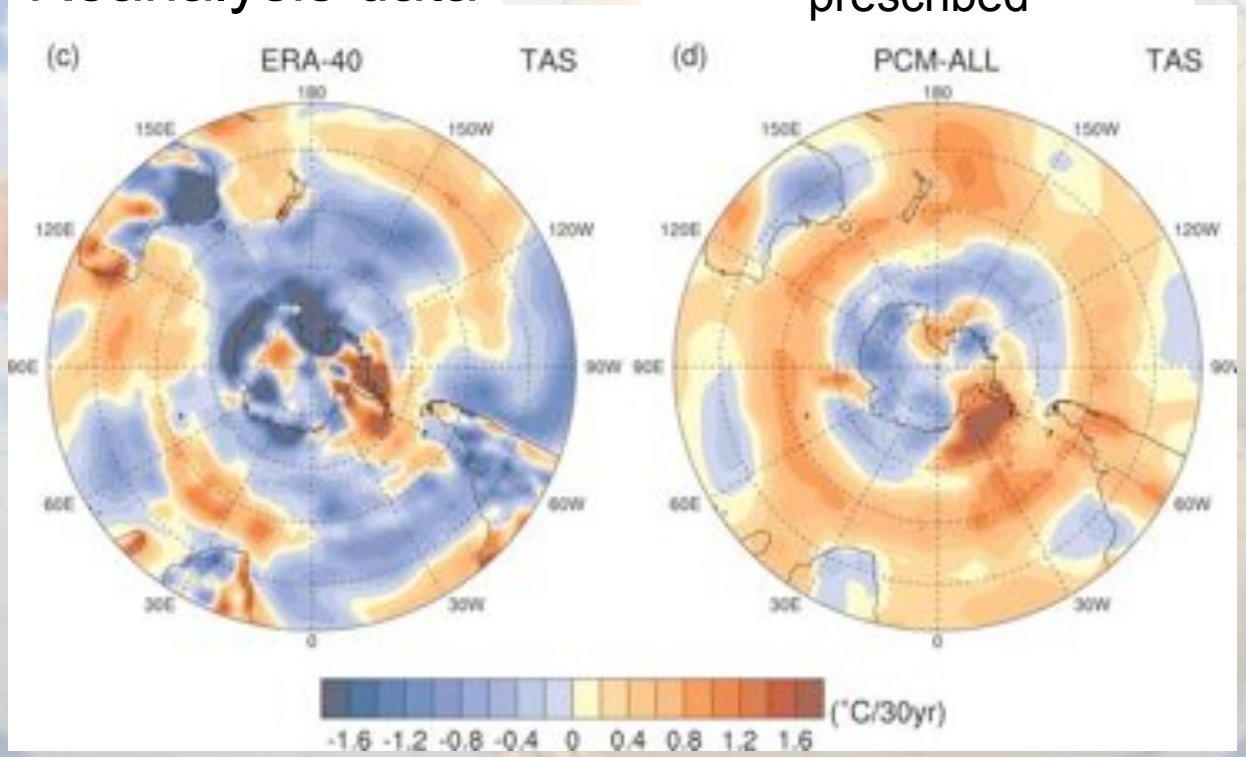


Neff et al., 2008

Summer-fall surface air temperature trend

Reanalysis data

Model with ozone & CO_2 prescribed



Modeled trends are somewhat weaker than observed

Modeling study: Arblaster and Meehl, 2006

The prevailing view

"In contrast [to the Arctic], within the past two decades sea ice extent and temperatures in the Antarctic have not been unusual in any season, except along the Antarctic Peninsula…"

"In the Antarctic, a strengthening of the atmospheric circulation around the continent has occurred in recent decades due to seasonal stratospheric ozone depletion and greenhouse gas increases.

As levels of stratospheric ozone recover, increased temperatures are expected on the central plateau and coastal areas of Antarctica."

Overland et al., 2008, *EOS*

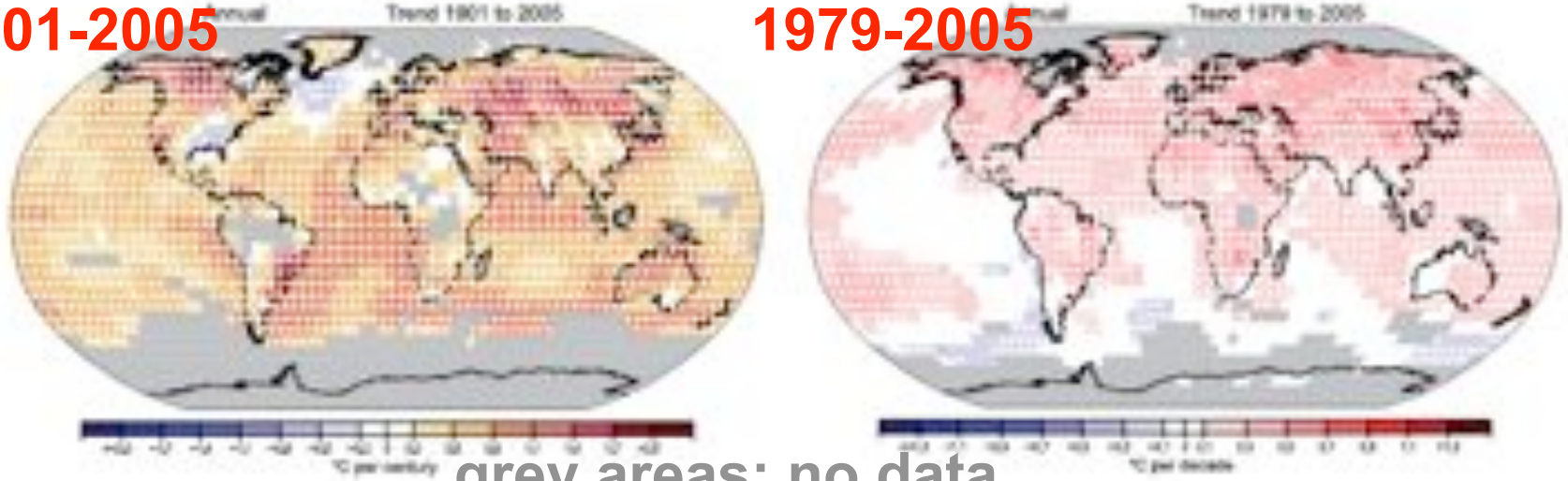
The Antarctic ‘data hole’

occurs in the 2001 and 2007 IPCC reports

Temperature trends

1901-2005

1979-2005



grey areas: no data

IPCC Report, 2007

The Antarctic ‘data hole’

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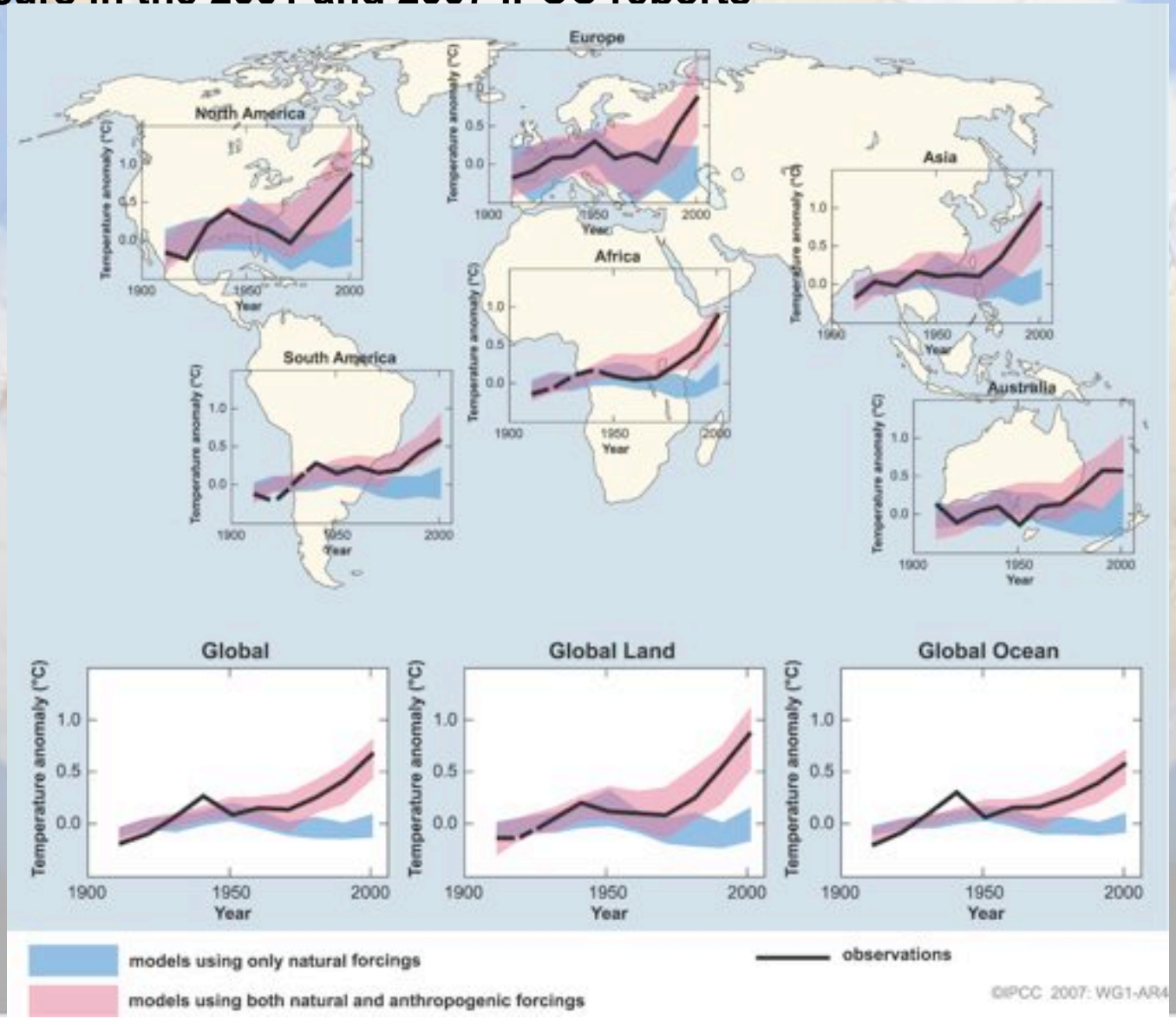
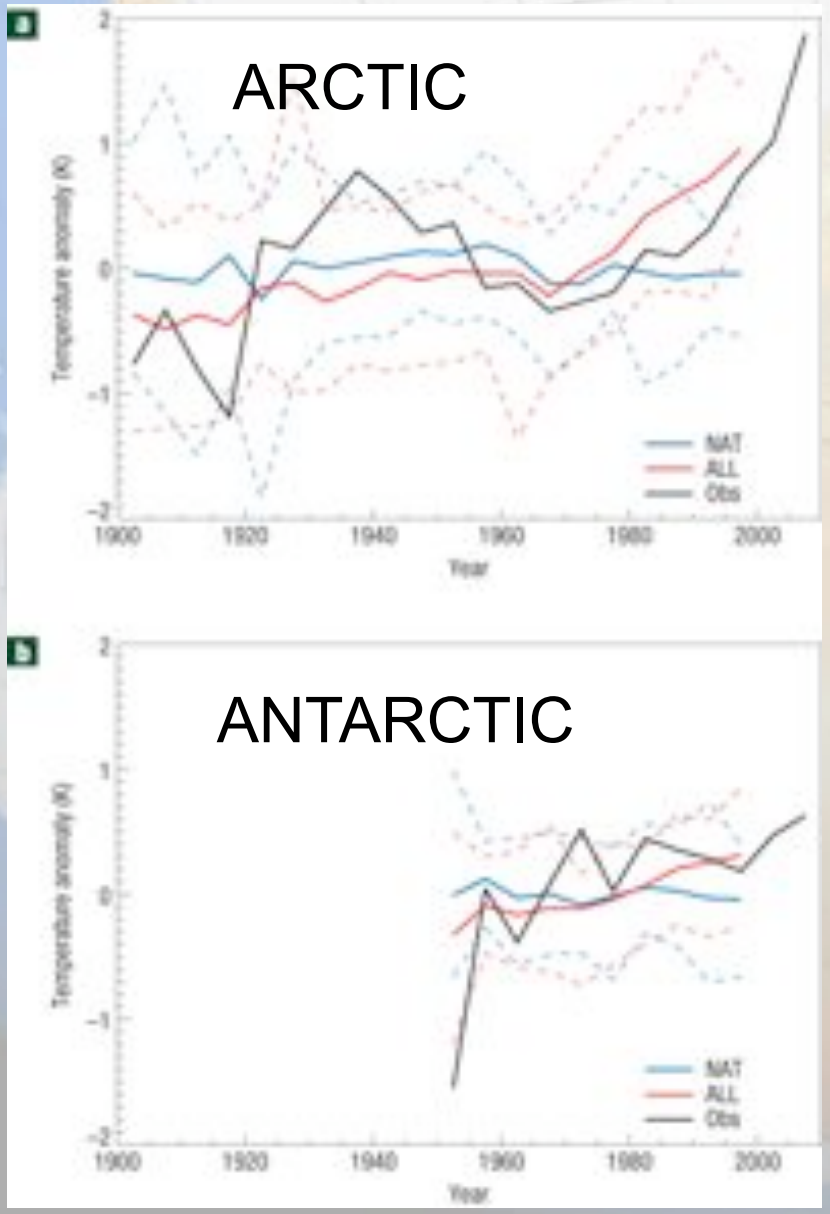
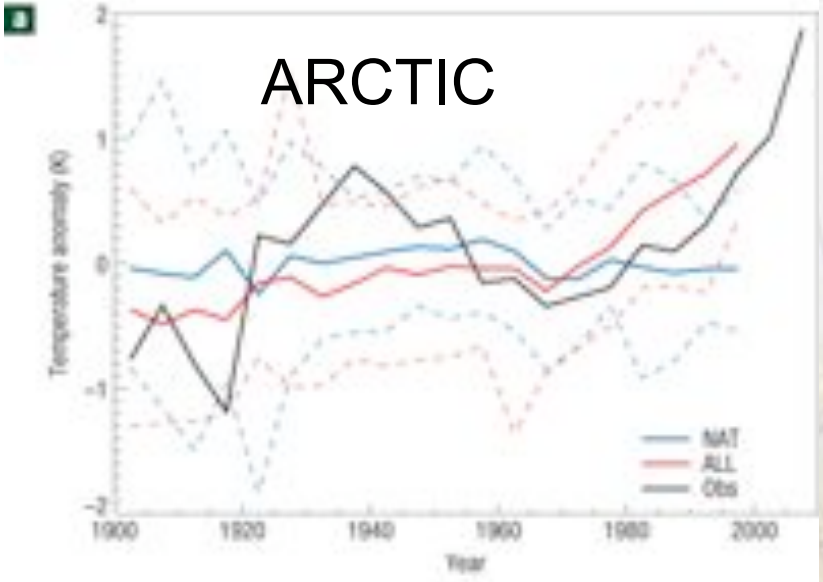


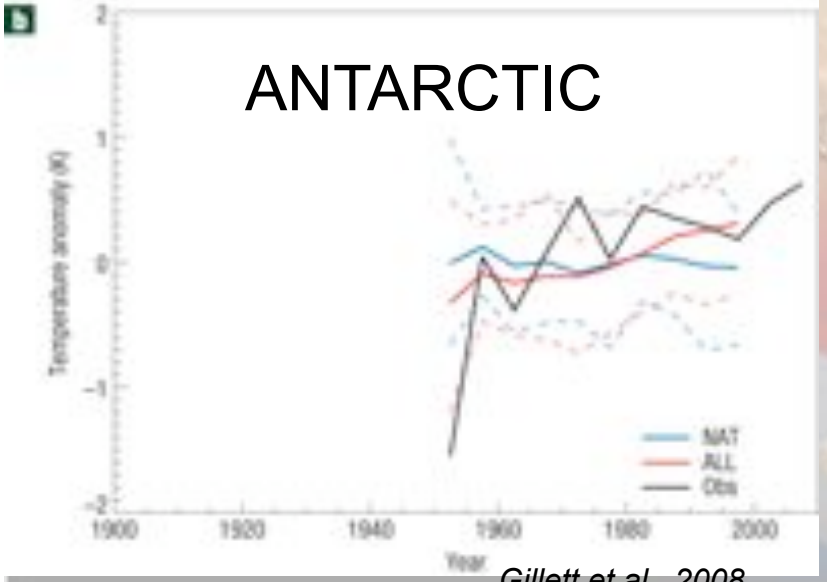
Attributing Antarctic climate change



Gillett et al., 2008

Attributing Antarctic climate change





Gillett et al., 2008

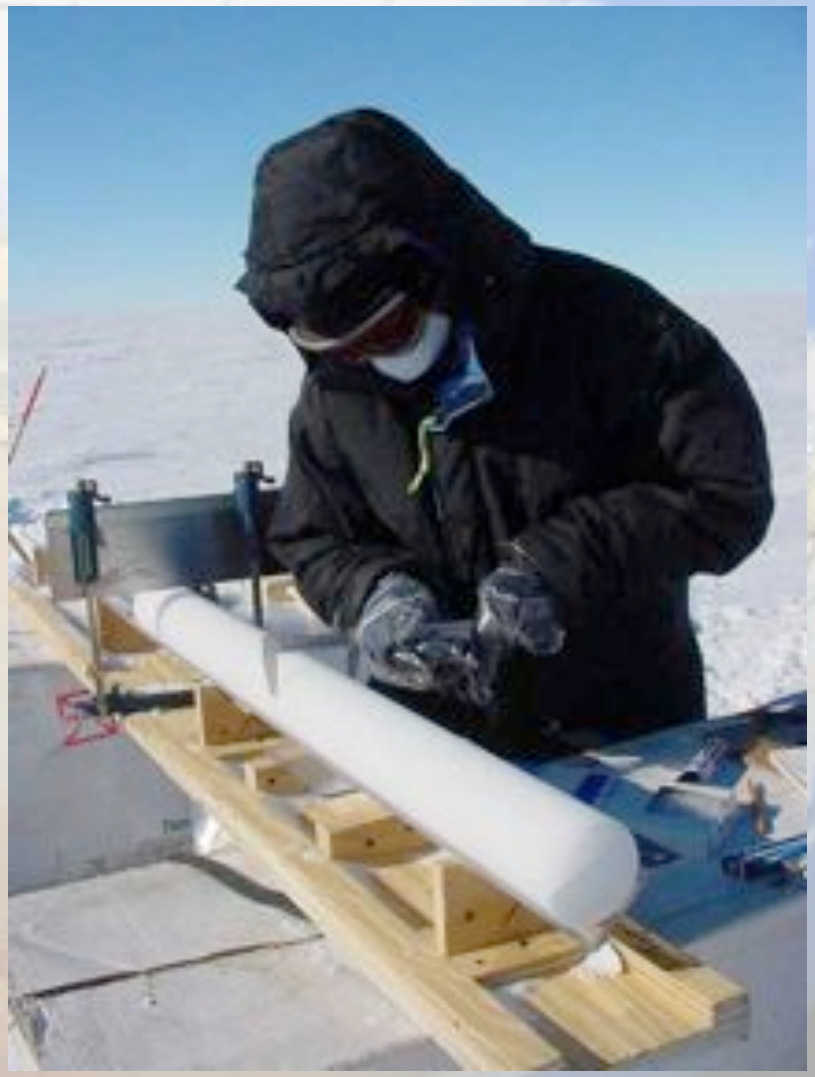
Standard deviation of temperature and SLP

Continent	Surface Area (10^6 km^2)	σ_{SLP} (hPa)	$\sigma_{2m\ temp}$ (K)
Europe	7.5	0.62	0.61
Asia	44.7	0.29	0.36
N. America*	21.1	0.39	0.53
S. America	17.5	0.24	0.21
Africa	29.6	0.36	0.23
Australia	8.1	0.75	0.32
Antarctica	12.7	1.73	0.56

* Excludes Greenland

Monaghan and Bromwich, 2008

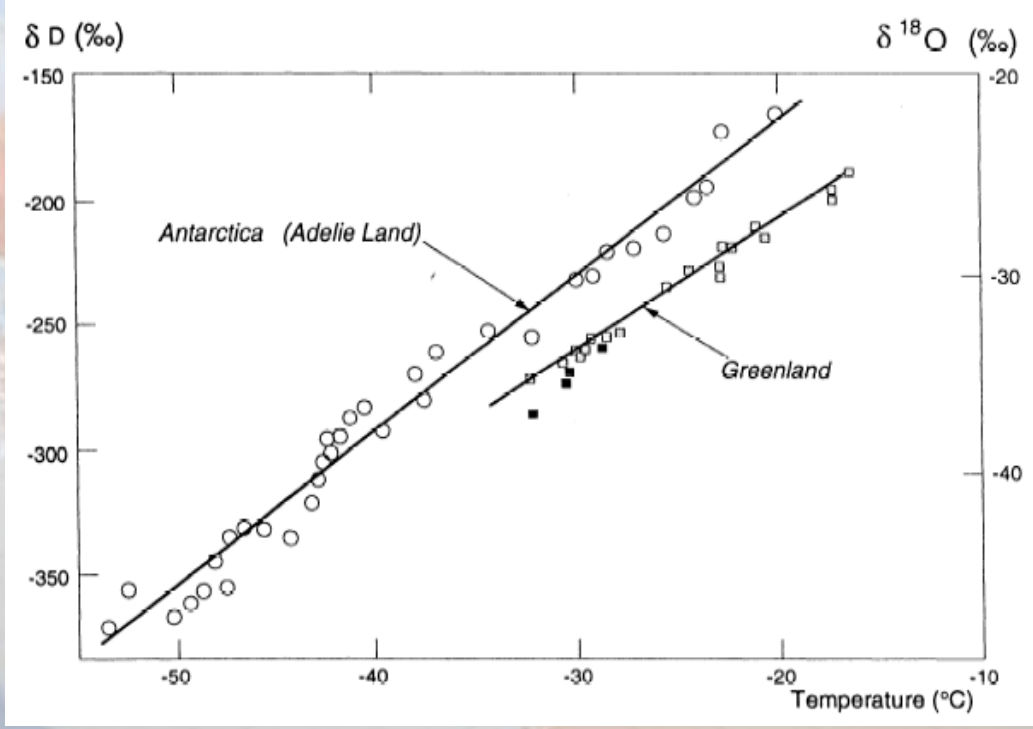
1) Ice cores & stable isotopes



Ice coring in West Antarctica

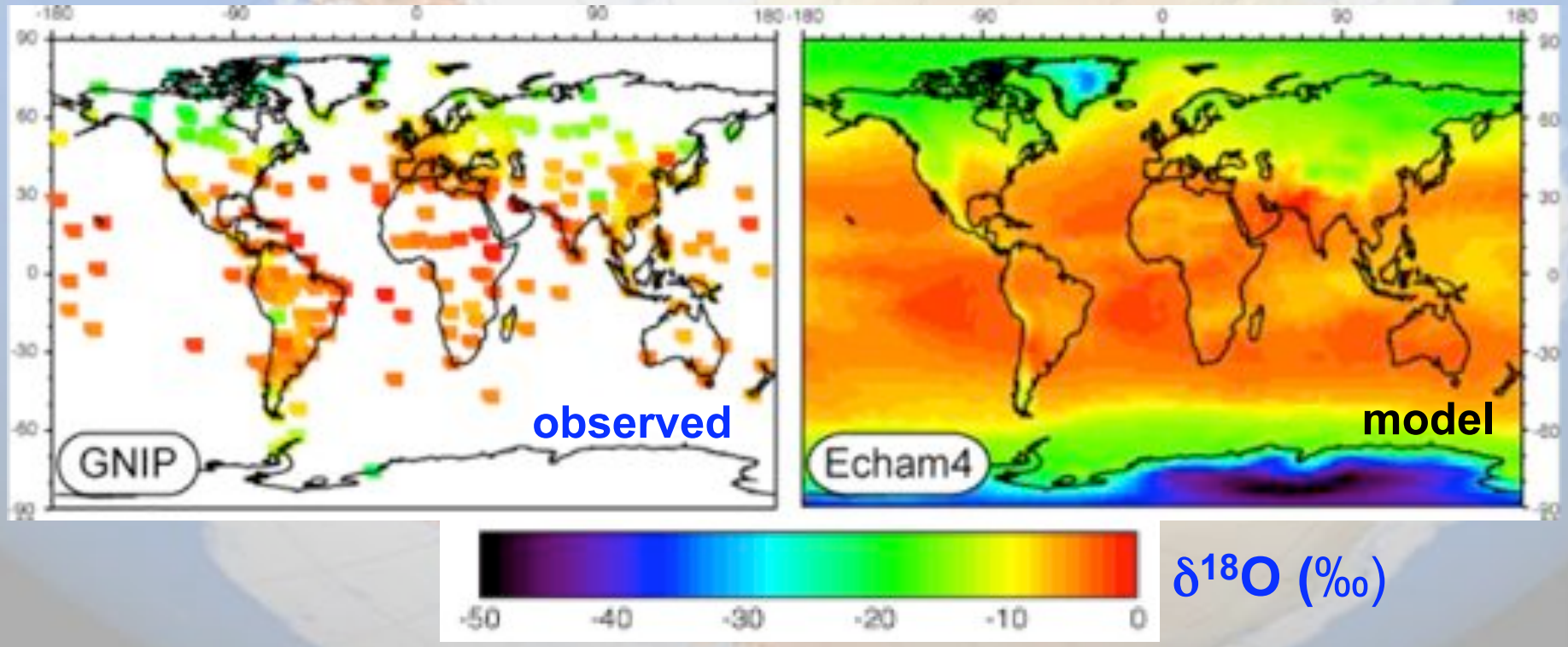
Isotope-temperature relationship: spatial

Local mean annual temperature vs δD in Antarctica and Greenland (***observed spatial slope***) (Jouzel et al., 1997)



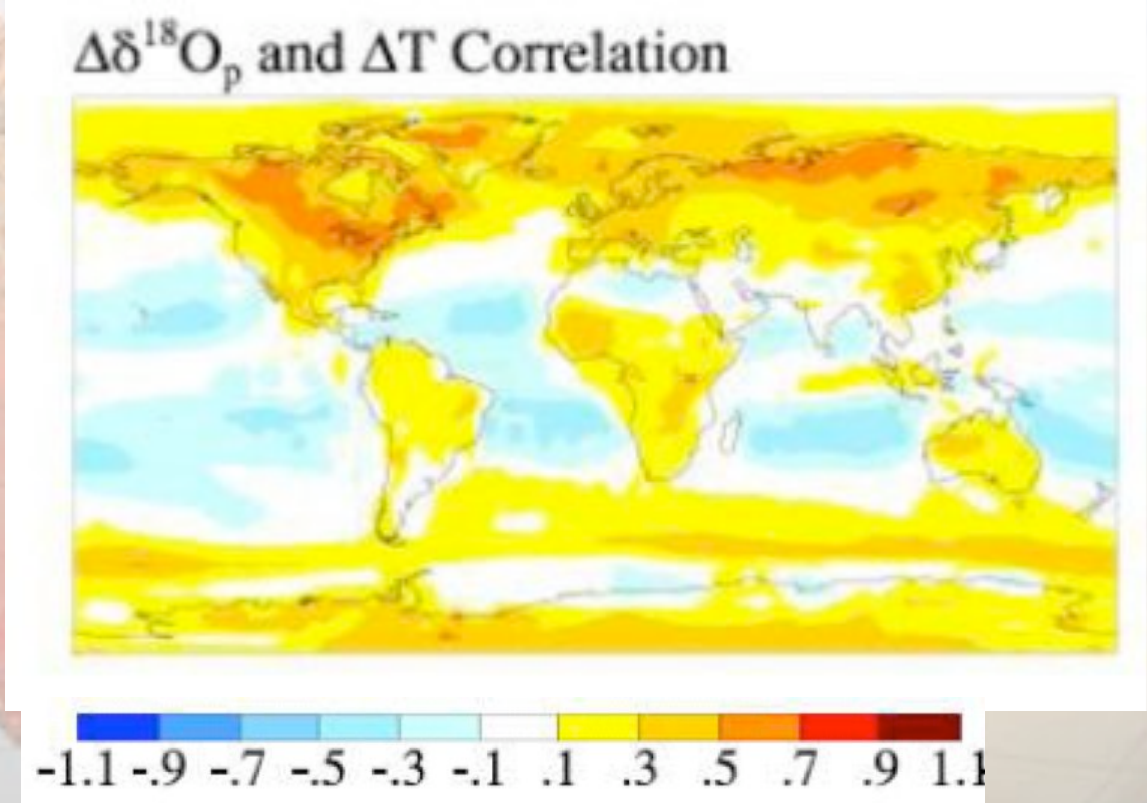
Climatology of $\delta^{18}O$, observed and modeled

Climate models explicitly depict processes that Rayleigh distillation models cannot, such as advection, mixing and source changes. Improved characterization of time-evolving relationships.



D. Noone

Isotope-temperature relationship: interannual

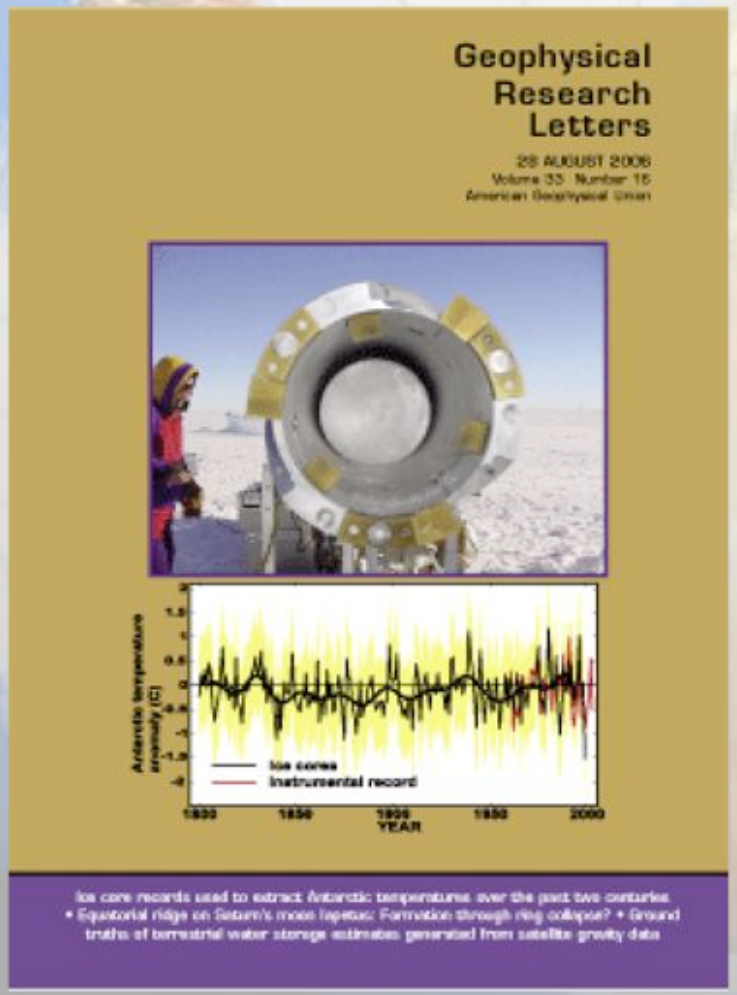


Schmidt et al., 2007

1) Introduction

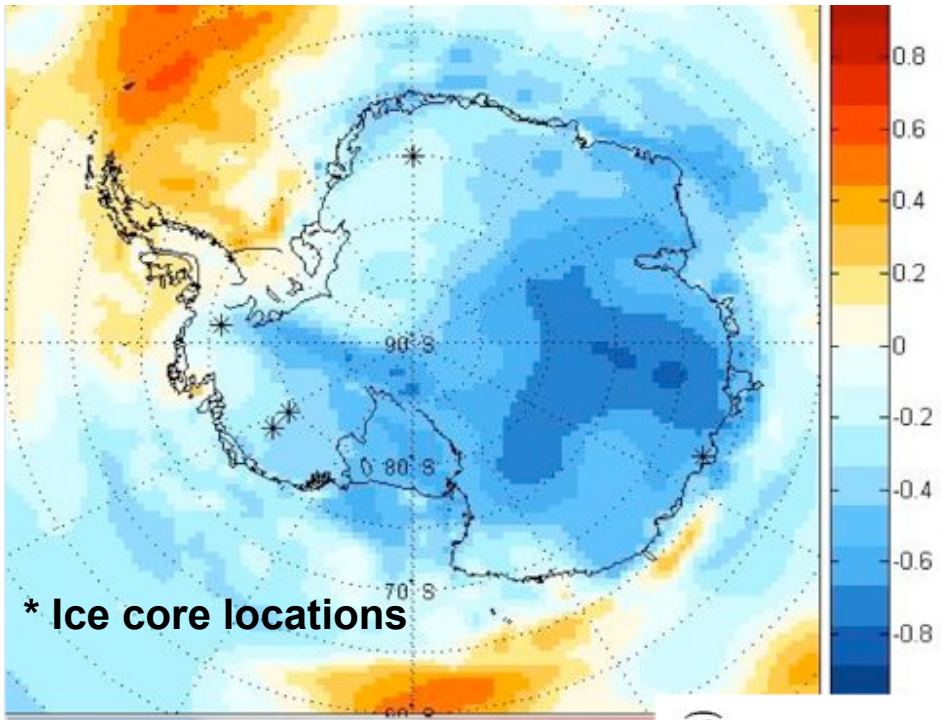
2) **Back 200 years**

Schneider et al. 2006, *GRL*

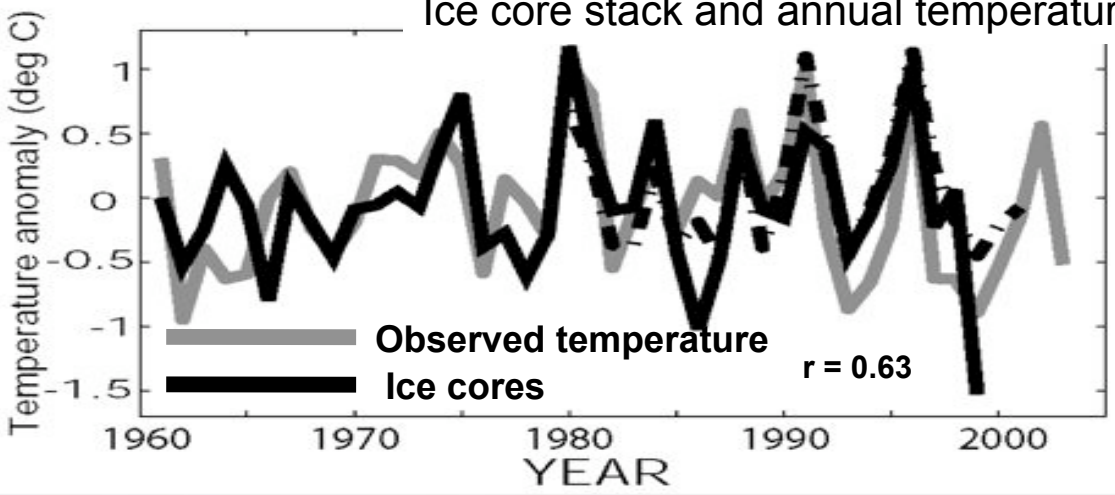


Antarctic temperature – ice core $\delta^{18}O$ relationship

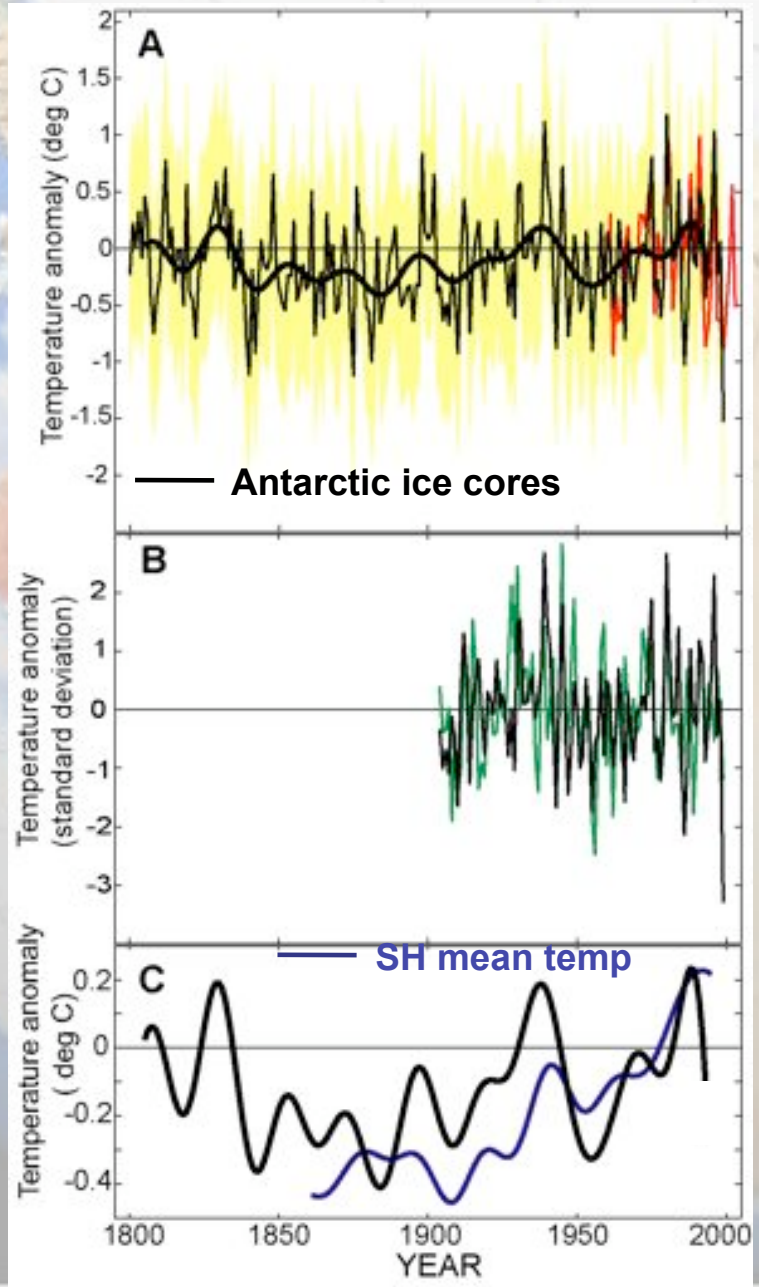
Correlation of ice core stack with gridpoint temperature



Ice core stack and annual temperature



Calibrated annual temperature reconstruction



Trend 1856-1998:
+0.23 ± 0.21 °C 100 yr^{-1}

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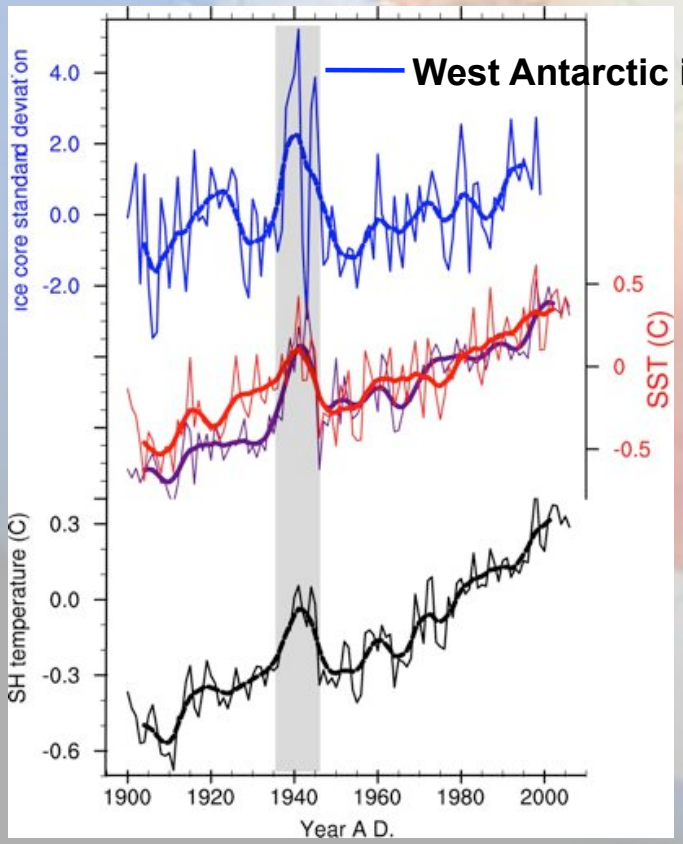
Schneider et al. 2006, *GRL*

3) West Antarctica, 20th Century

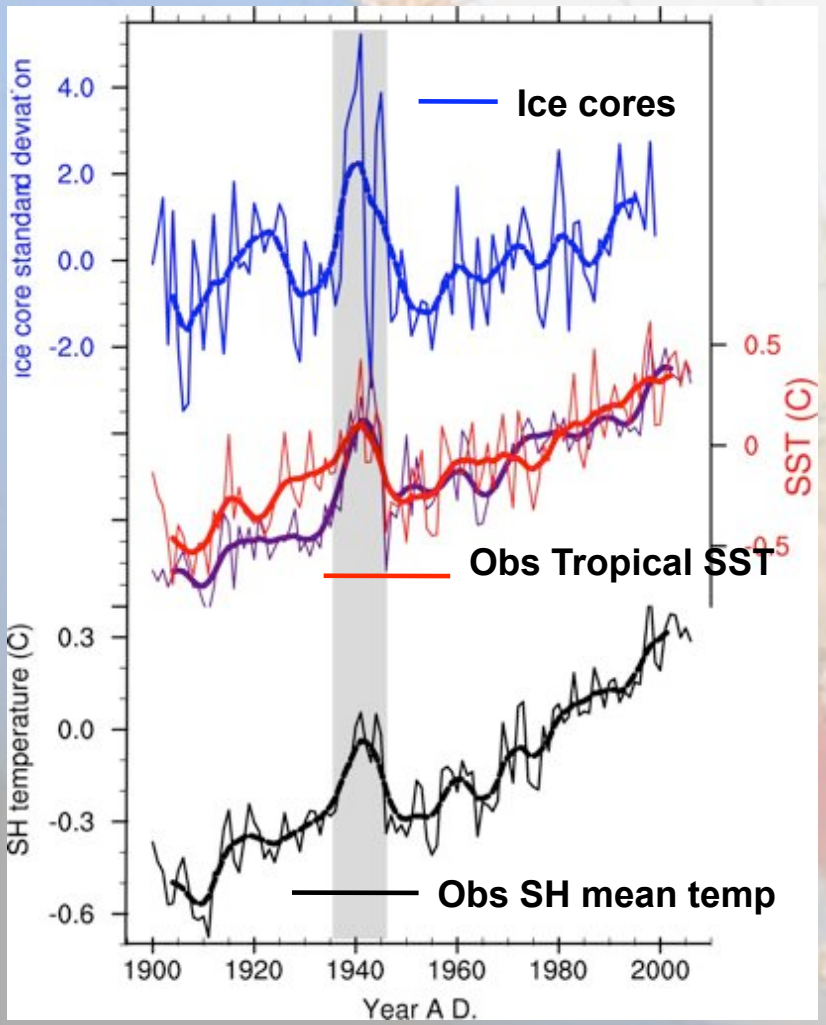
Schneider and Steig 2008, *PNAS*

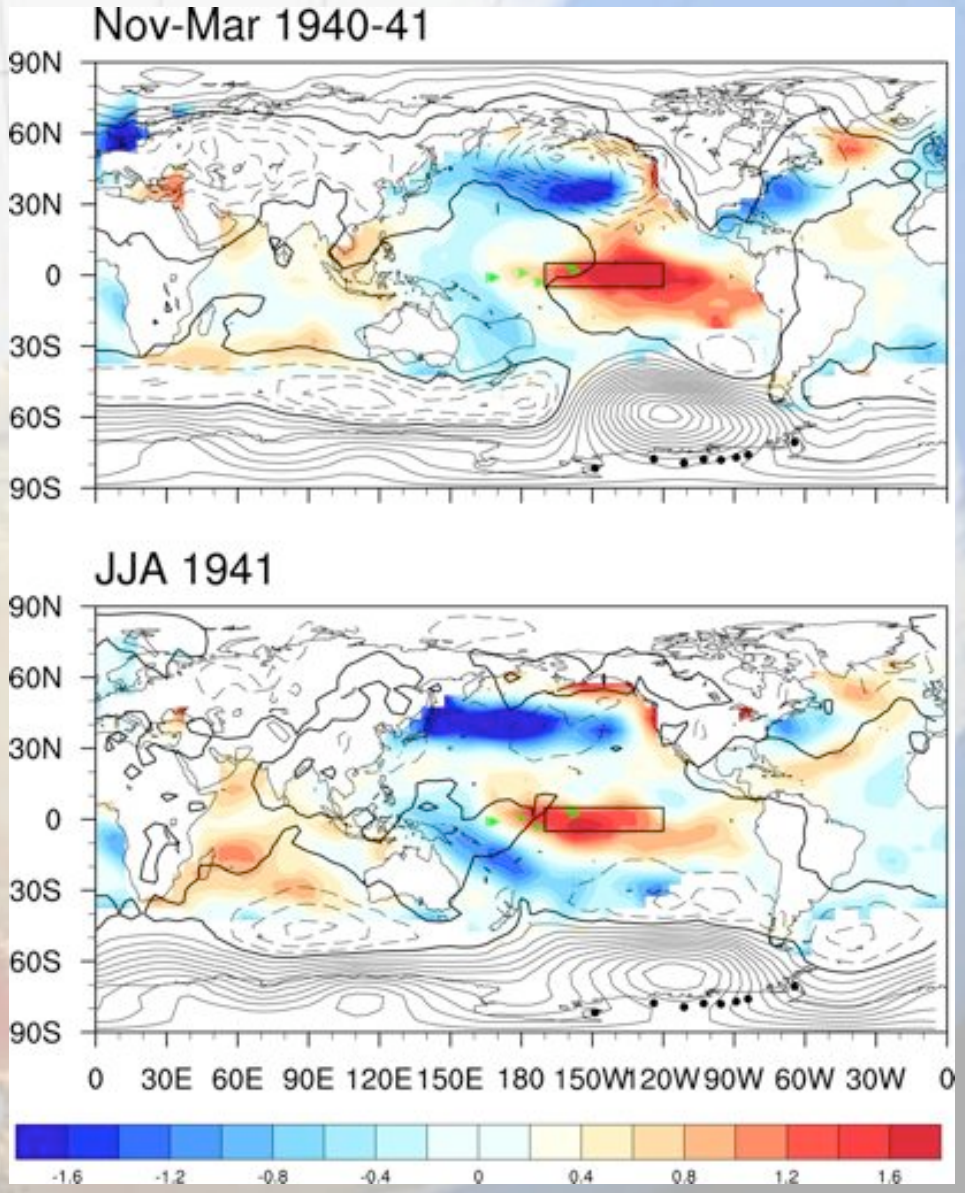


Trend 1900-1999:

1°C 100 yr^{-1} (barely not sig.)

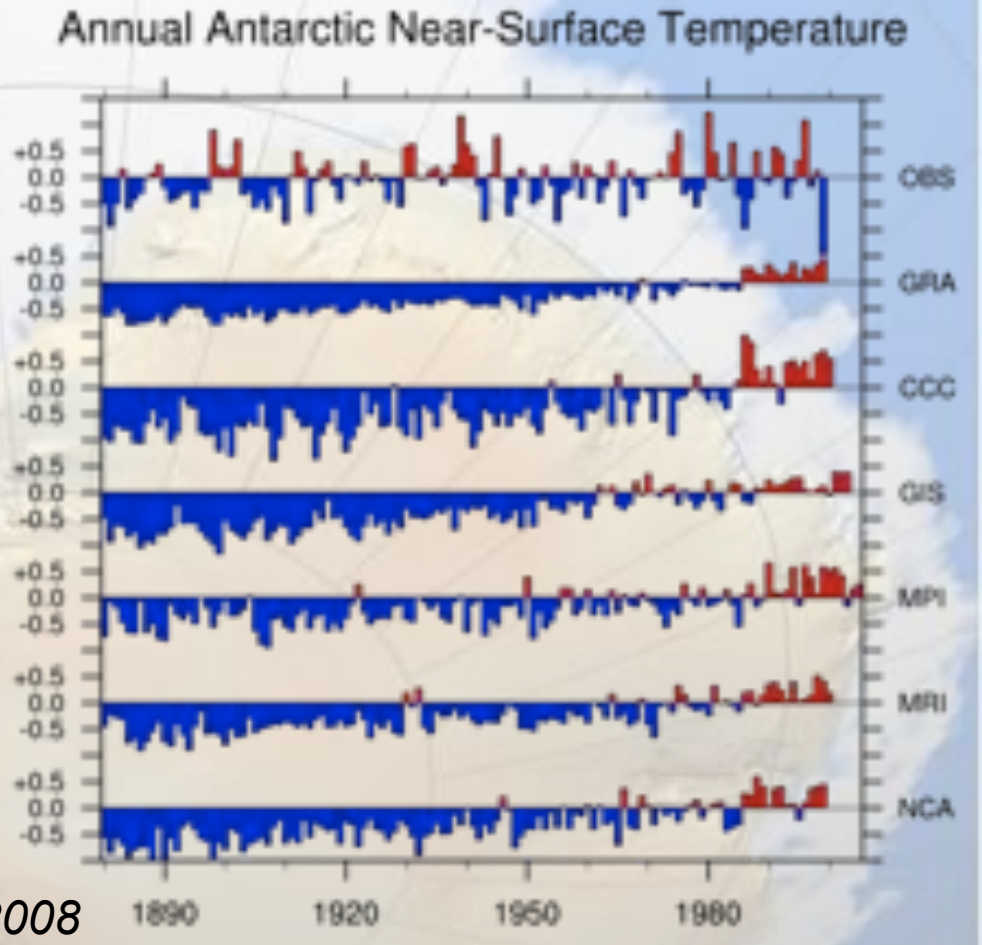
High variability is partly linked to the tropics





SST & SLP anomalies during the 1939-42 El Nino, the longest 'major' El Nino of the 20th-Century

Reconstructed temperature compared with IPCC models



Monaghan et al., 2008

Table 2. Antarctic NSAT and Snowfall Trends and Confidence Intervals ($p < 0.05$) for Observations and GCMs for Various Periods and Seasons[a]

Variable	Units	Period	Season	Schneider	Monaghan	GCM 'GRA'	Min GCM	Max GCM
Temperature Trend	K century^{-1}	1880–1999	Annual	0.20 ± 0.32	-±-	*0.75*[b] *± 0.07*[b]	*0.52*[b] (MPI)	*0.97*[b] (CCC)
Temperature Trend	K century^{-1}	1960–1999	Annual	0.13 ± 1.95	0.06 ± 2.03	*1.44*[b] *± 0.34*[b]	*0.68*[b] (GIS)	*2.45*[b] (CCC)
Temperature Trend	K century^{-1}	1960–1999	DJF	-±-	1.09 ± 3.06	*1.11 ± 0.37*	0.06 (GIS)	*2.51* (CCC)
Temperature Trend	K century^{-1}	1960–1999	MAM	-±-	−0.61 ± 3.95	*1.48*[b] *± 0.57*[b]	0.77 (GIS)	*2.80*[b] (CCC)
Temperature Trend	K century^{-1}	1960–1999	JJA	-±-	1.56 ± 4.32	*1.88*[b] *± 0.67*[b]	1.06 (GIS)	*2.73*[b] (CCC)
Temperature Trend	K century^{-1}	1960–1999	SON	-±-	0.96 ± 2.92	*1.28*[b] *± 0.59*[b]	0.71 (GIS)	*1.78*[b] (CCC)
Snowfall Trend	mm century^{-1}	1955–1999	Annual	-±-	*32*[b] *± 31*[b]	*17*[b] *± 4*[b]	5 (GIS)	*26*[b] (CCC)
S/T Sensitivity	% K^{-1}	Varies[c]	Annual	-±-	*4.9 ± 4.9*	*5.5 ± 0.8*	*2.4* (MRI)	*7.1* (MPI)

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Schneider et al. 2006, *GRL*

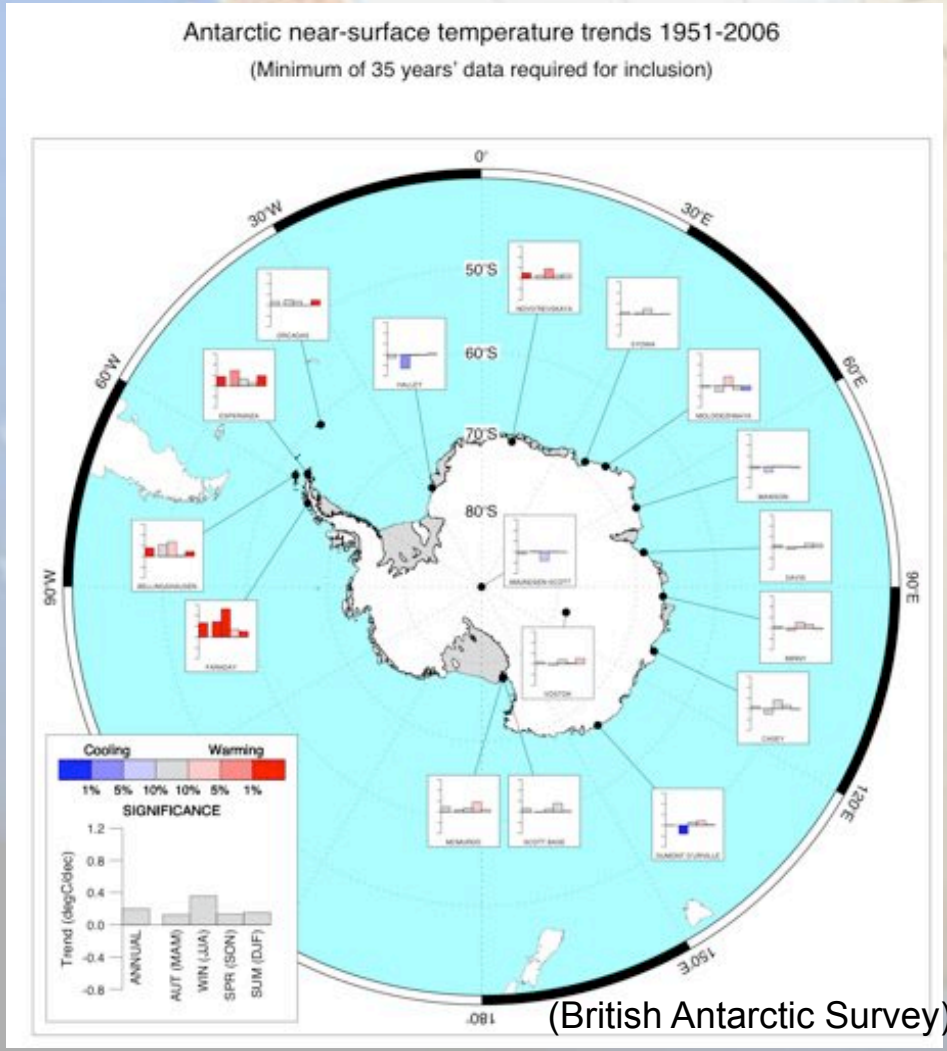
3) West Antarctica, 20th Century

Schneider and Steig 2008, *PNAS*

4) The last 50 years in detail

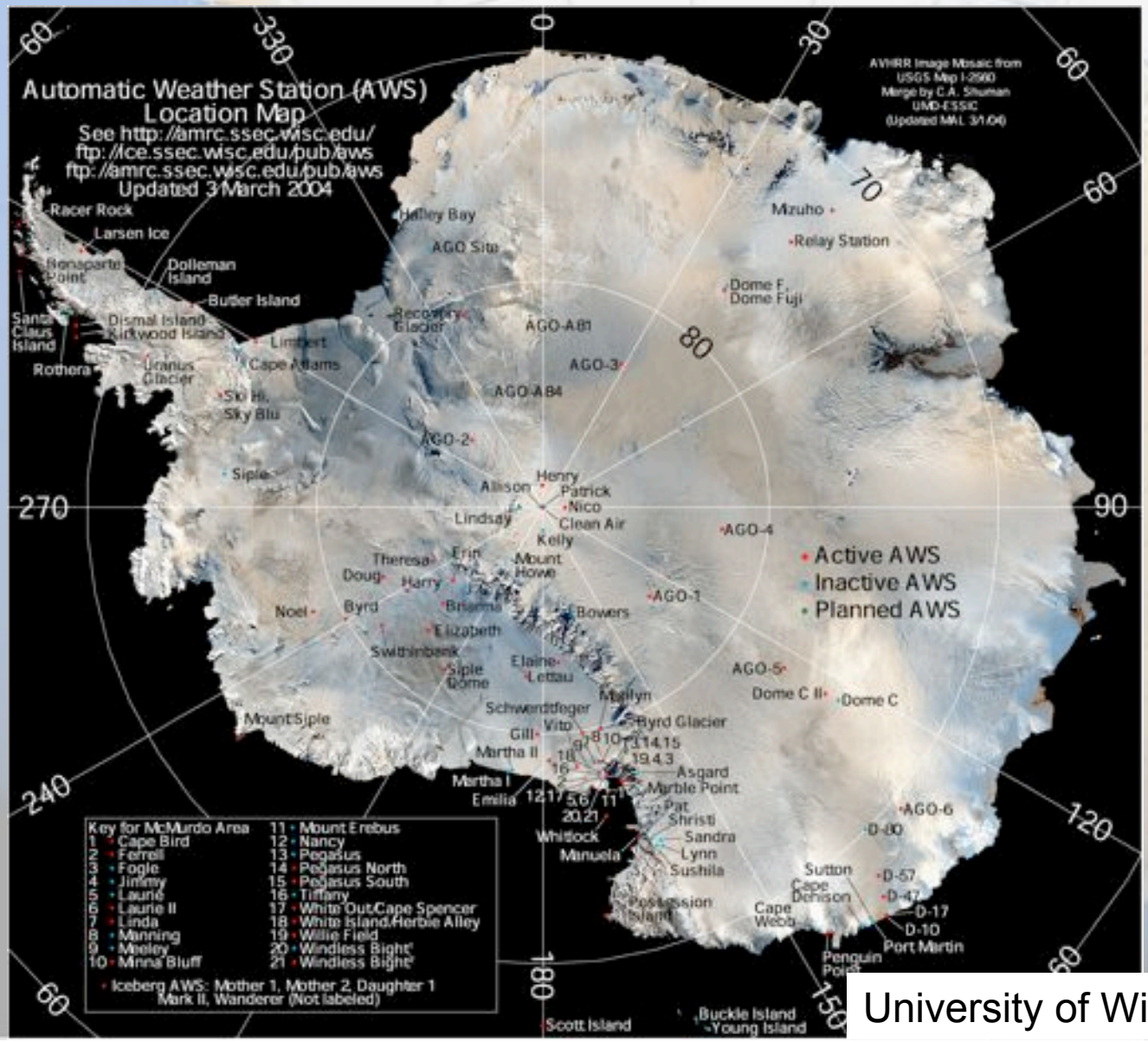
Steig, Schneider et al. 2009, *Nature*

Still a ‘data hole’ (though ice cores help!!)… Only a handful of weather stations around the continent



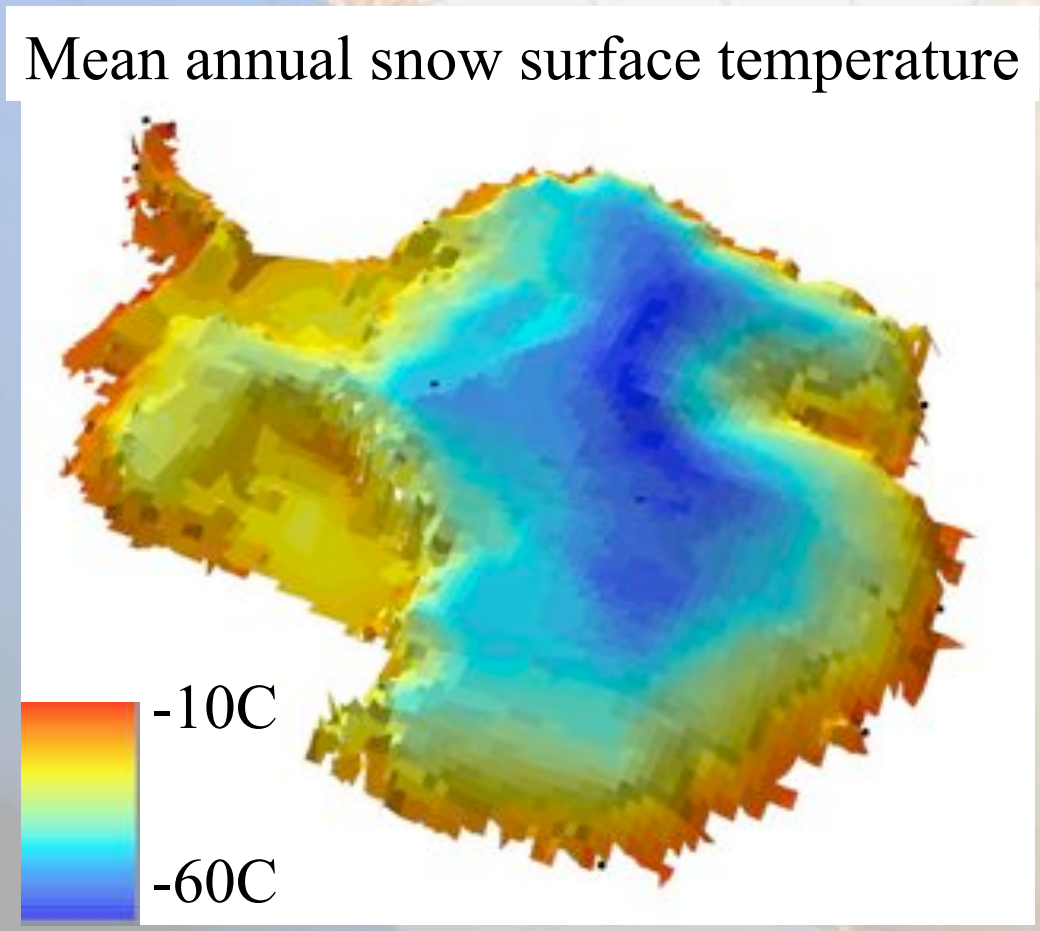
(British Antarctic Survey)

More (widely scattered and discontinuous) data do exist from Automatic Weather Stations (AWS)



University of Wisconsin

Satellite data: excellent spatial & temporal coverage since 1982

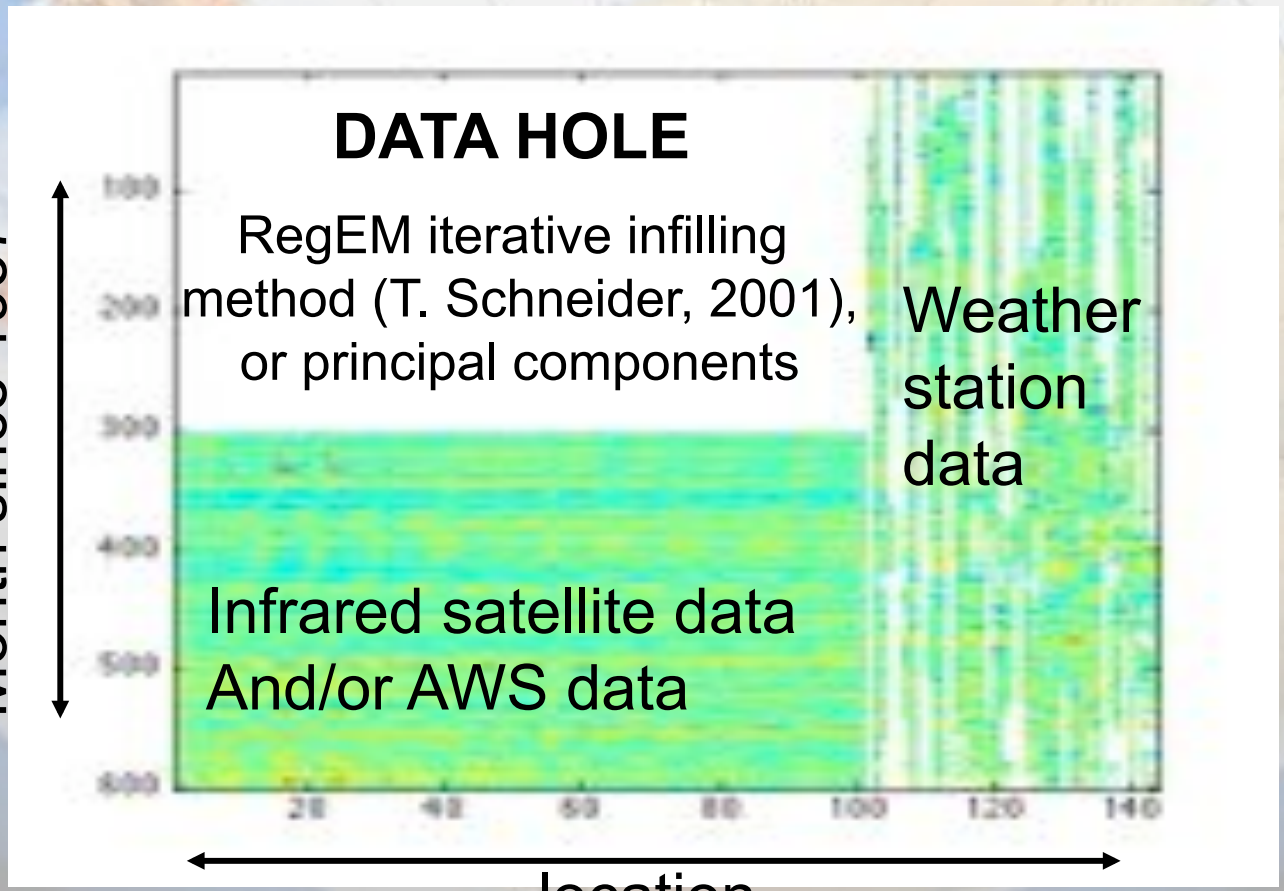


- Monthly snow-surface temperatures from infrared channels on AVHRR

- Clear-sky in best case; can be difficult to cloud mask over the ice sheet

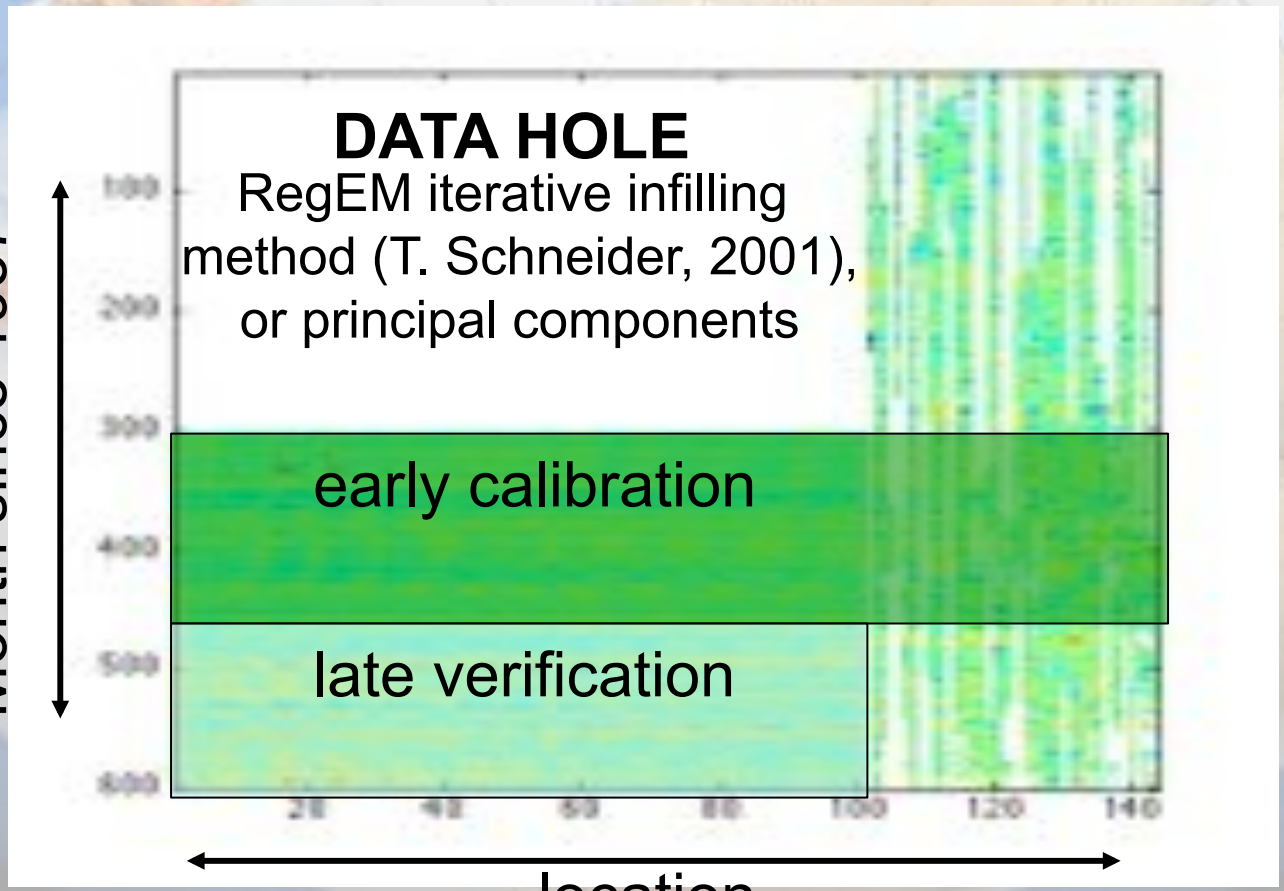
Comiso, 2000; Schneider et al., 2004

Combination of weather station and satellite data



Steig et al., 2009

Combination of weather station and satellite data



Steig et al., 2009

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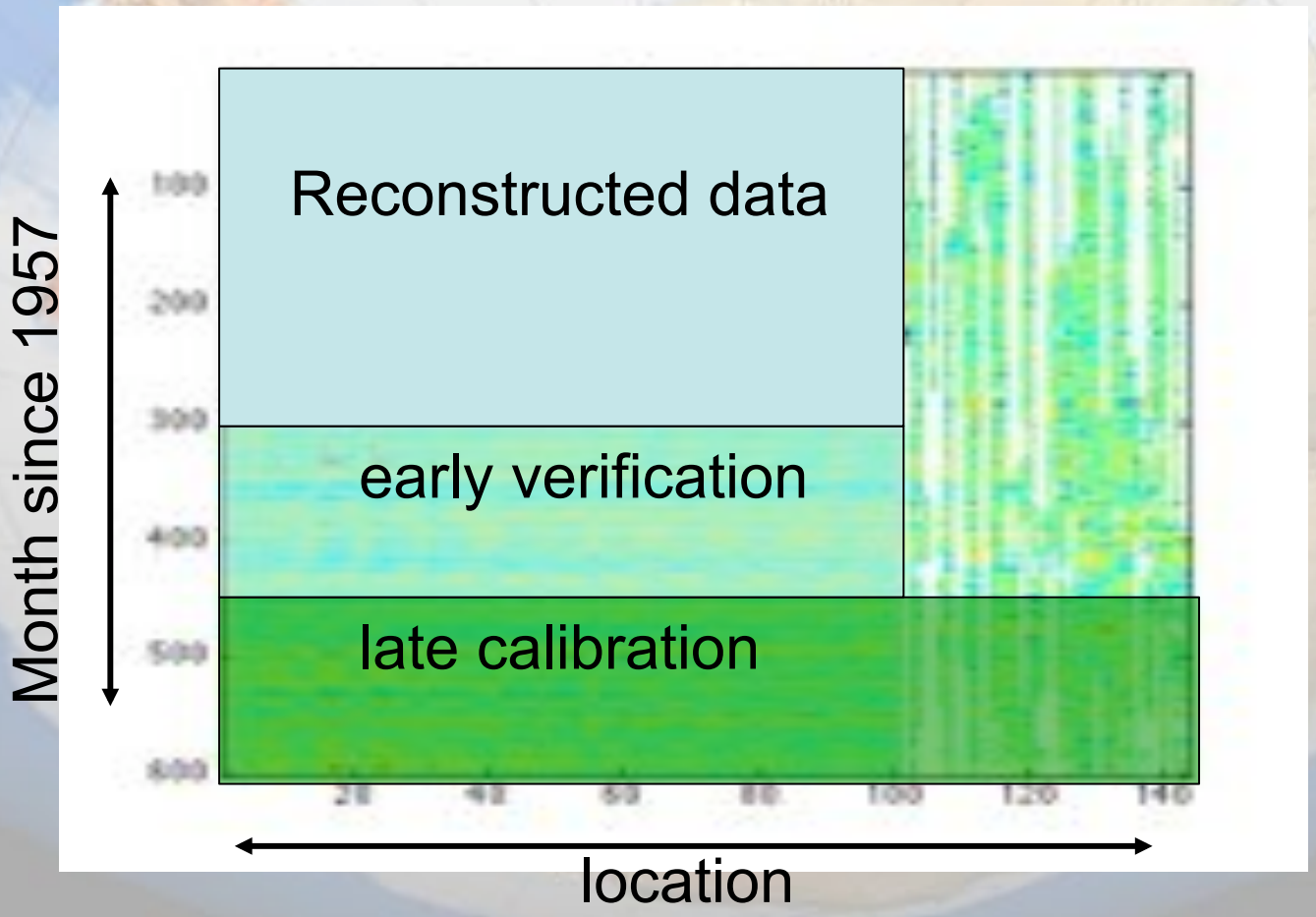
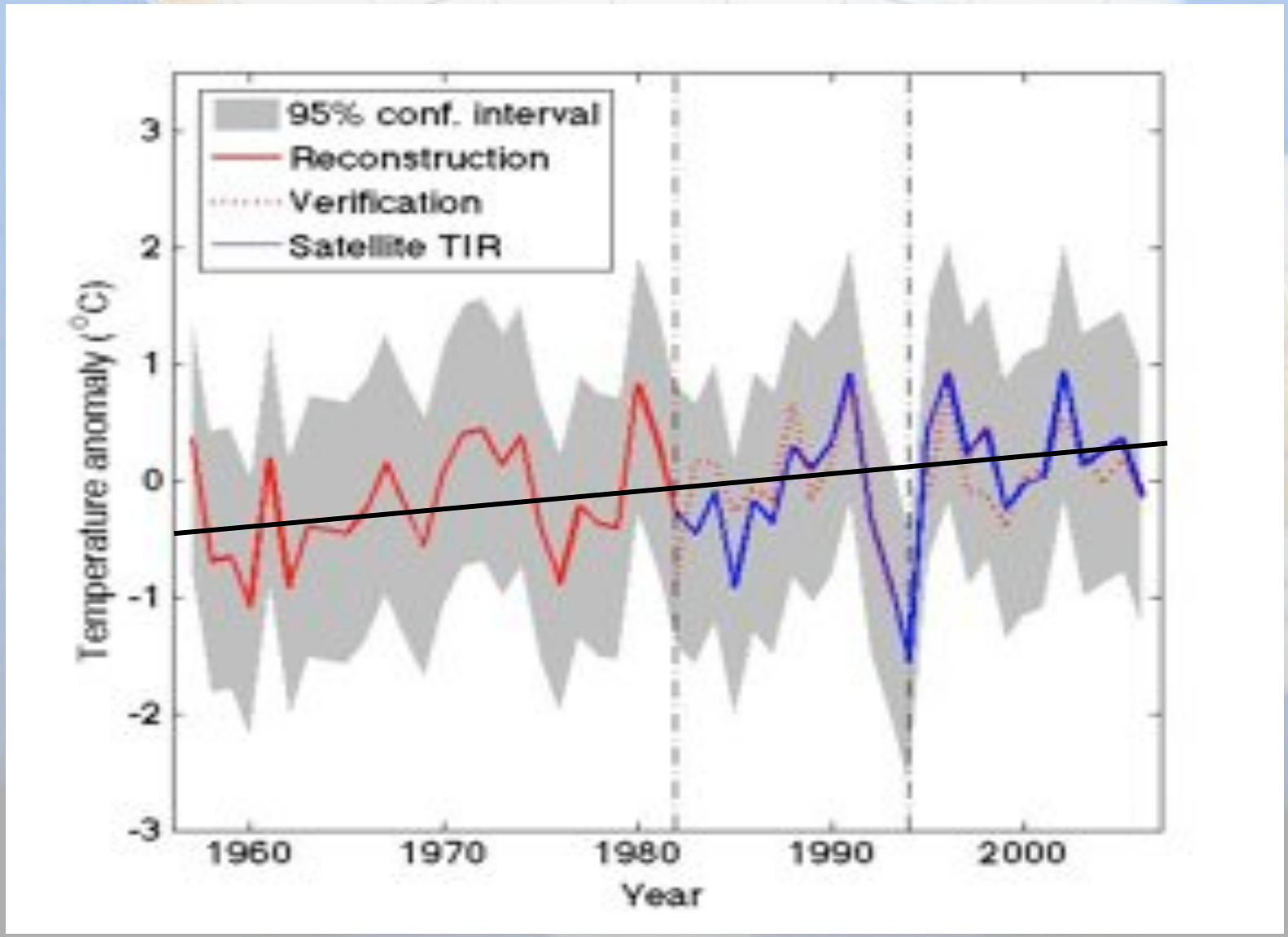


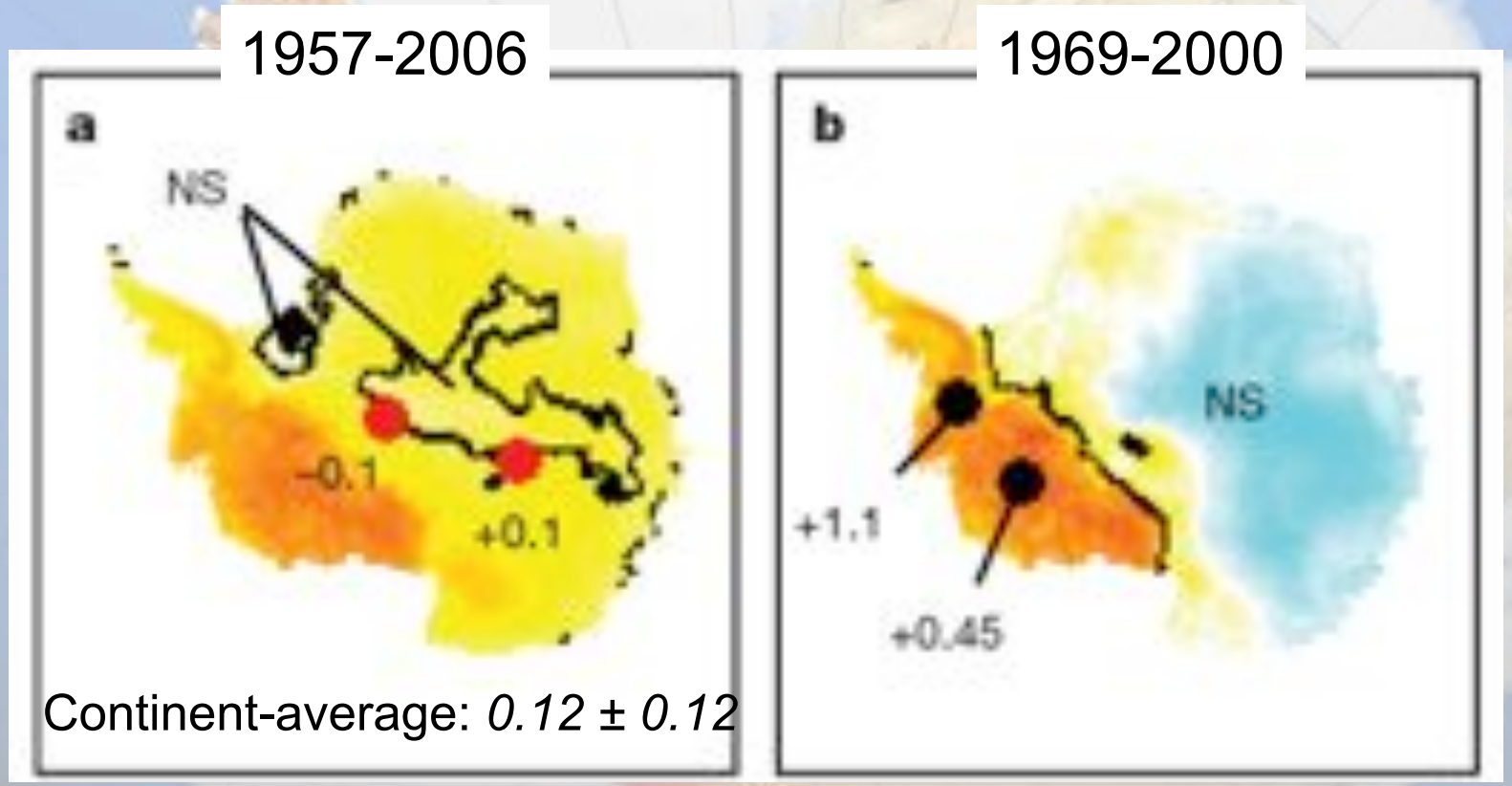
Steig et al., 2009

Reconstruction (1957-2006)



Steig et al., 2009

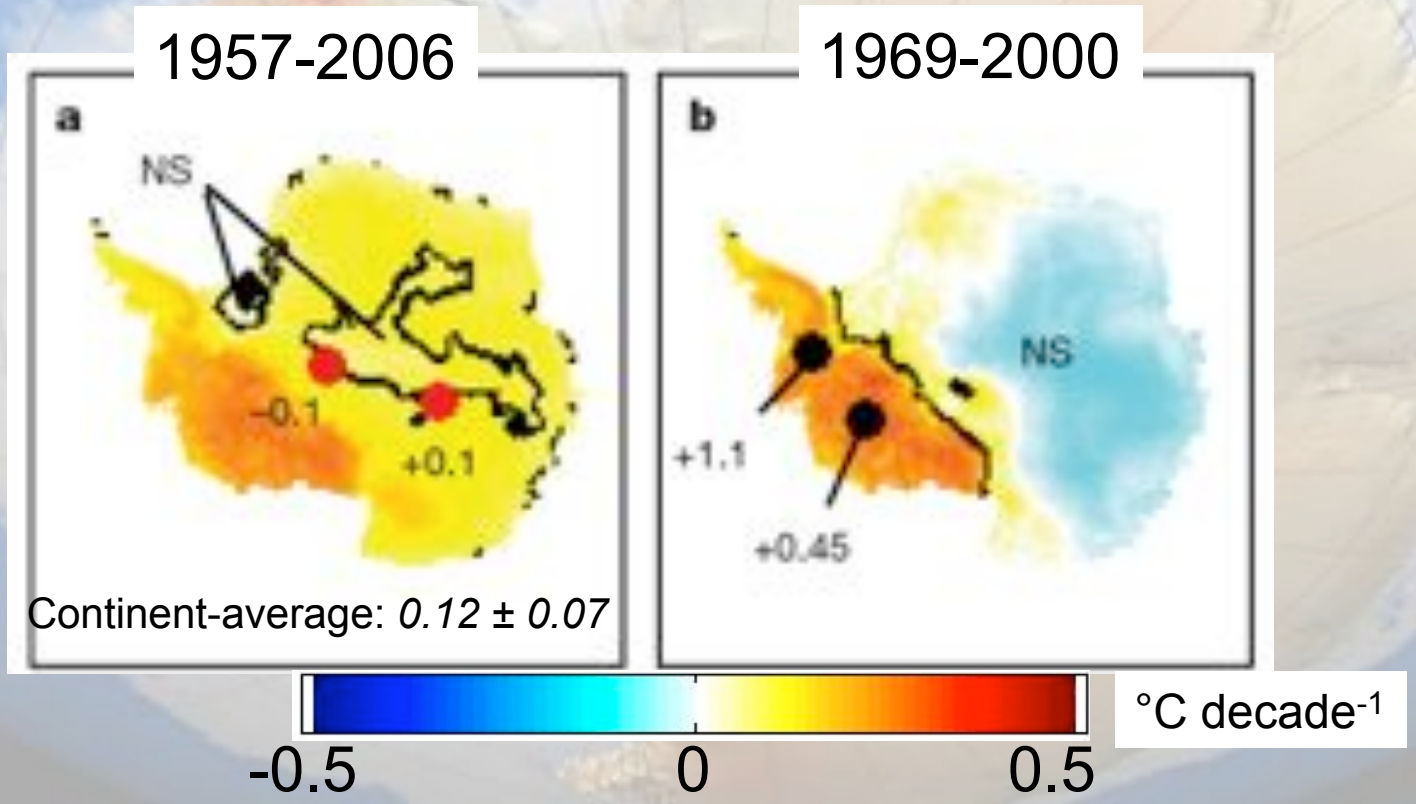
Annual trends



Steig et al., 2009

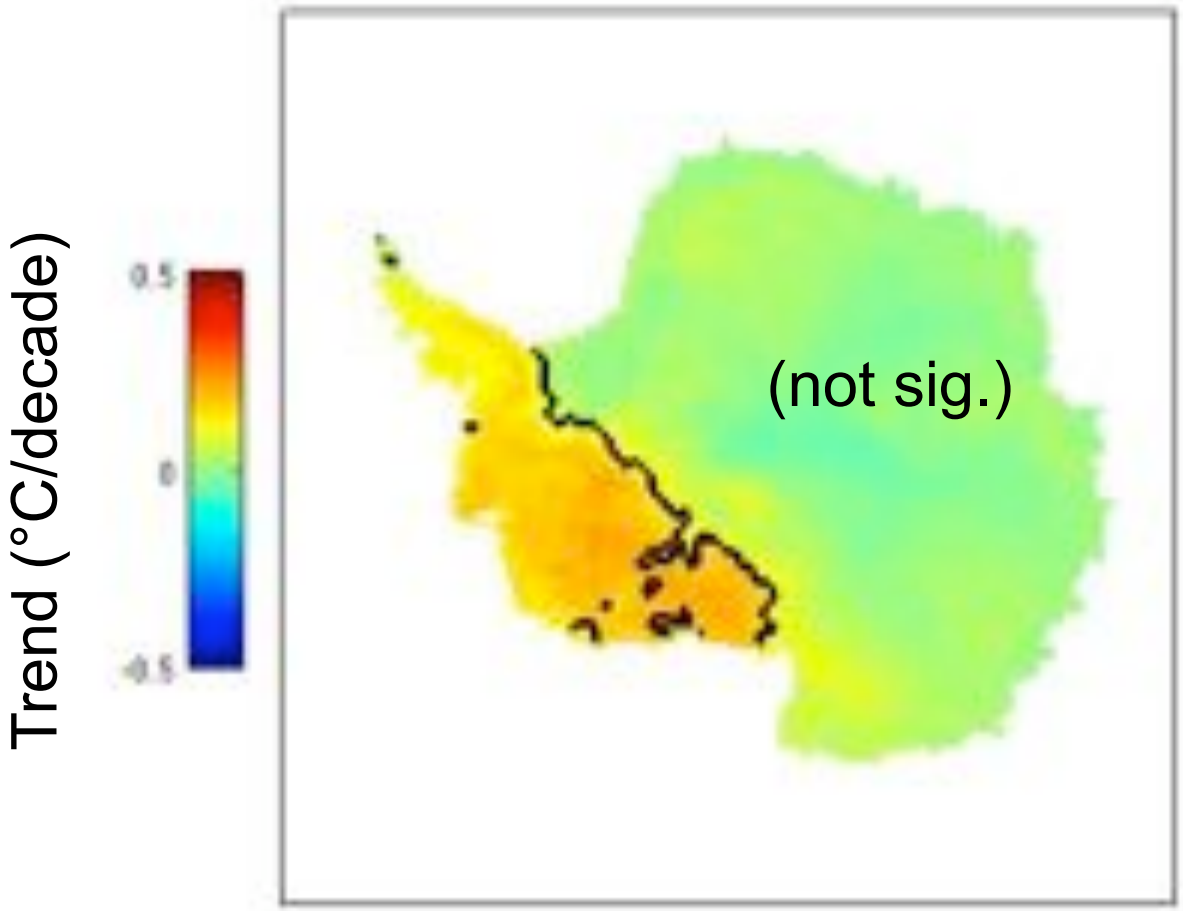
Annual trends

IPCC trend estimates, 1979-2005 (from CRU data)	
Global average	0.16 ± 0.05
Northern Hemisphere	0.23 ± 0.07
Southern Hemisphere	0.09 ± 0.04



Steig et al., 2009

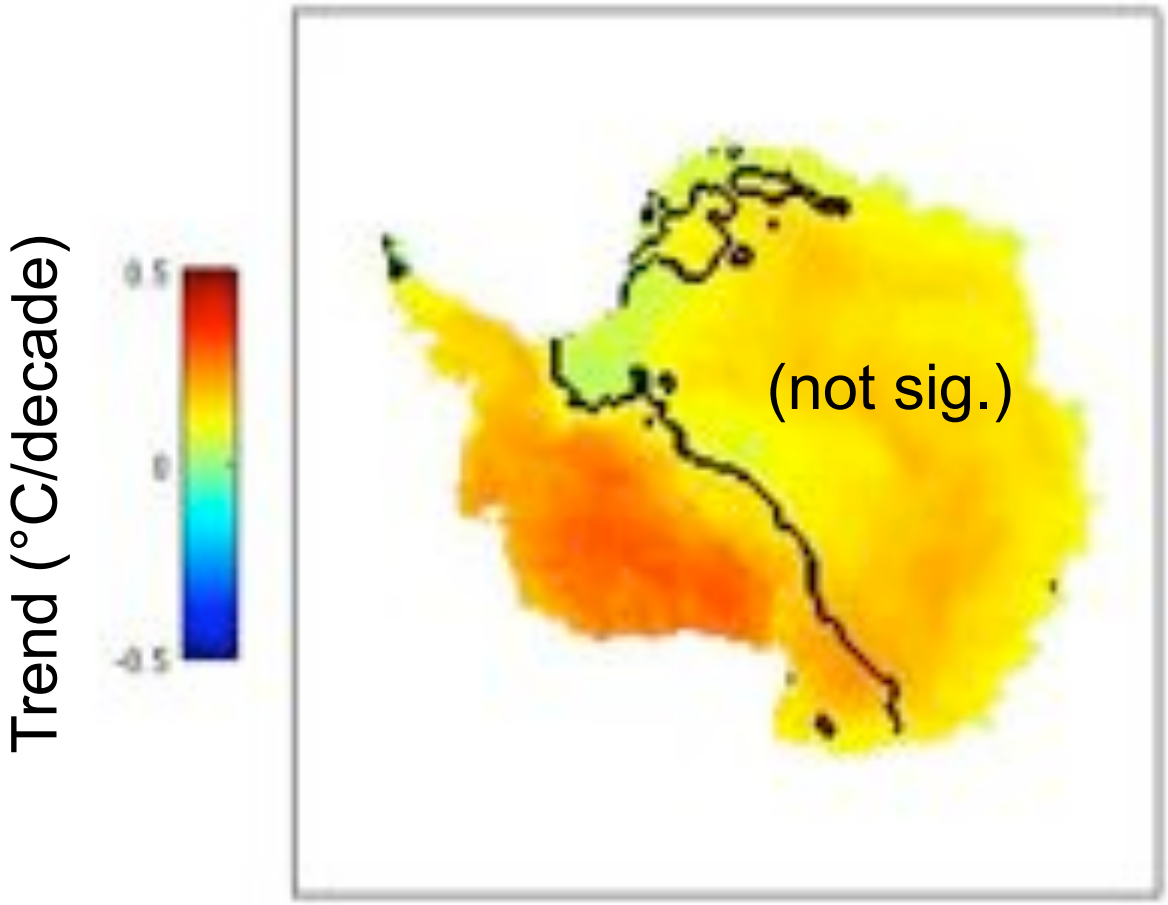
Autumn, 1957-2006



East Antarctic cooling primarily in autumn

Steig et al., 2009

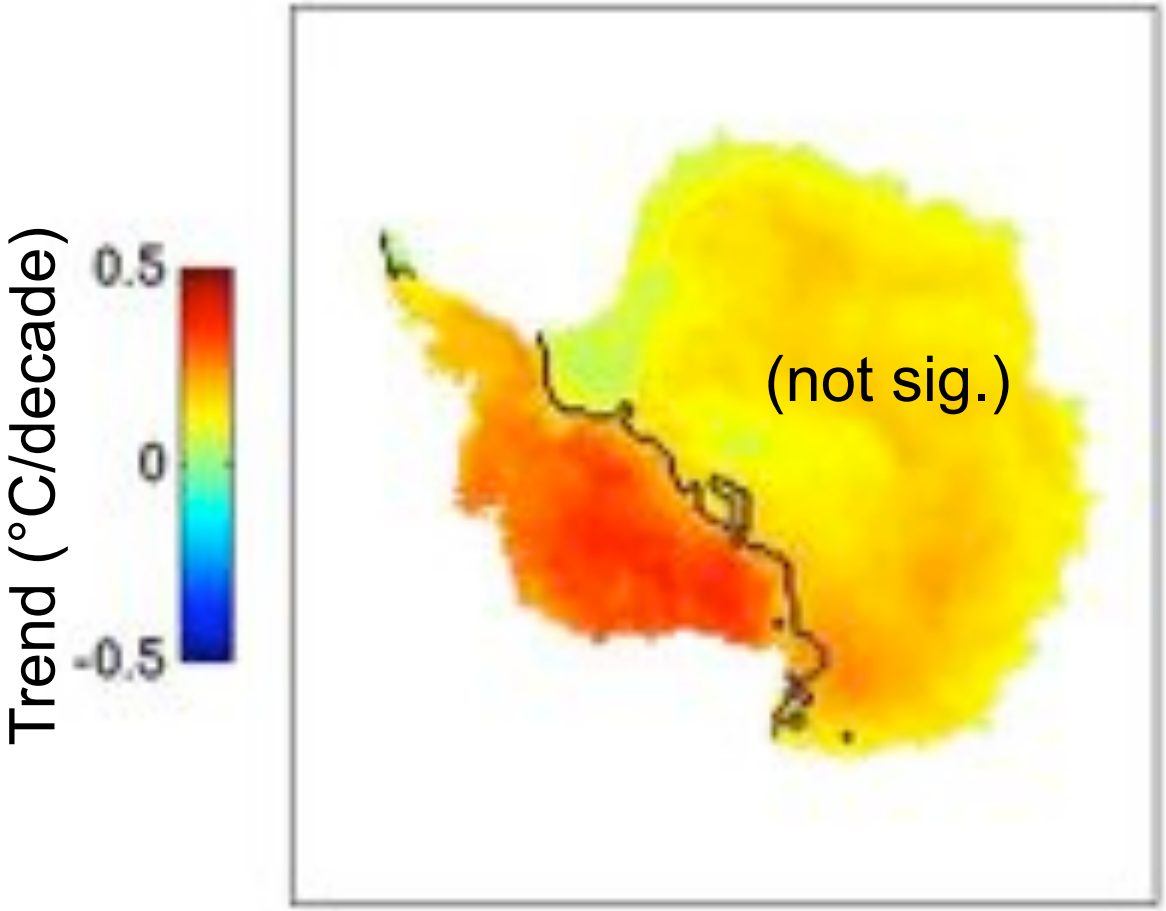
Winter, 1957-2006



Continent-average: 0.17 ± 0.2

Steig et al., 2009

Spring,1957-2006

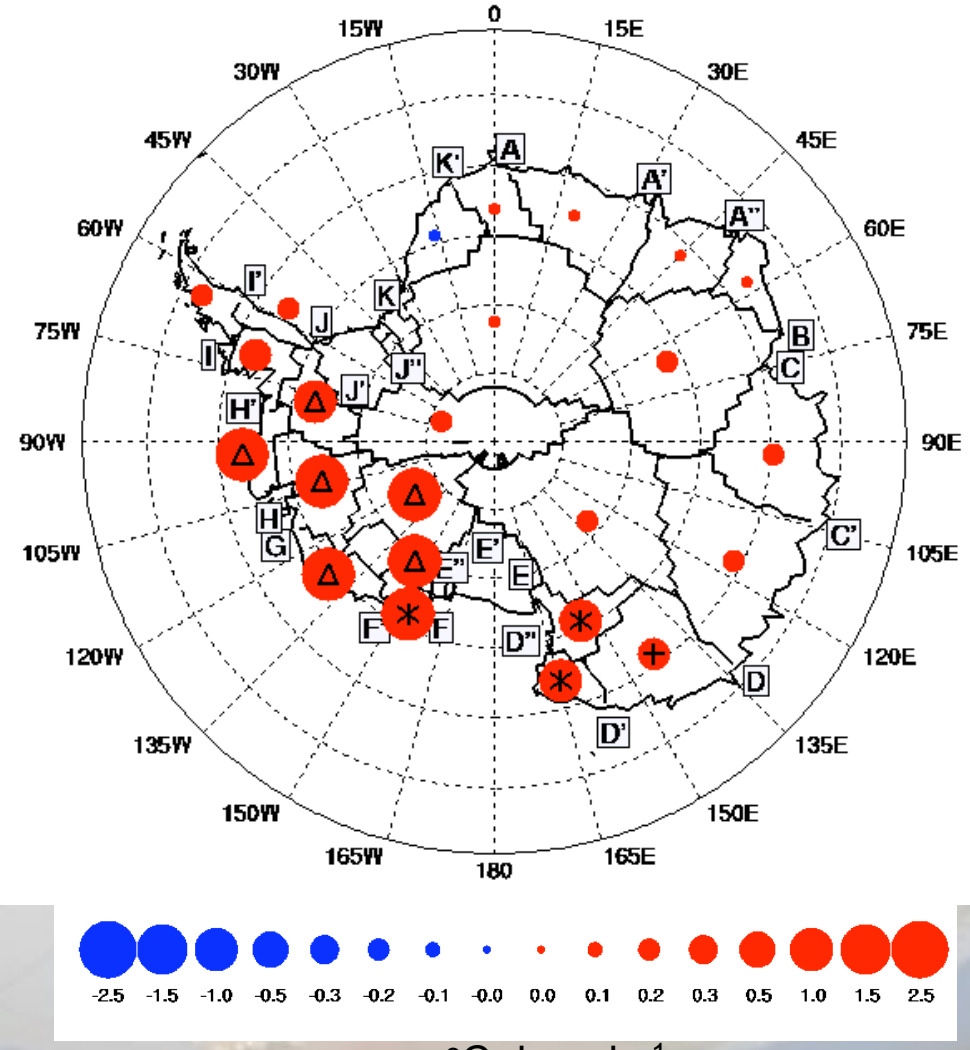


Continent-average: 0.16 ± 0.2

Steig et al., 2009

Confirmation from reconstruction that avoids satellite data

Spring temperature trends 1960-2007



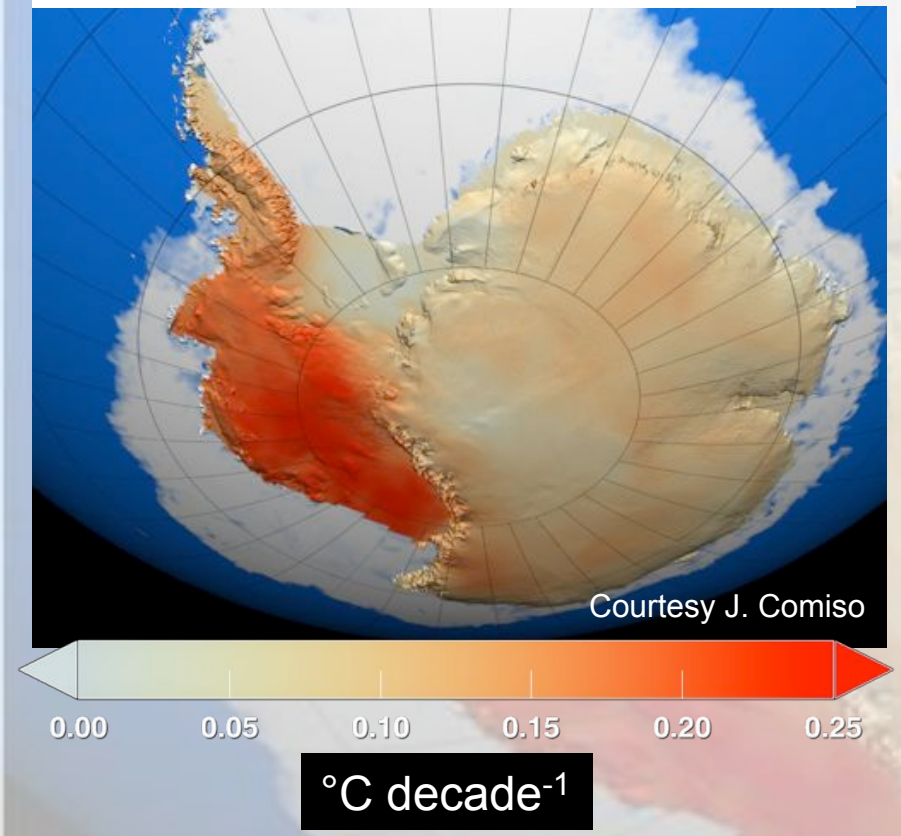
Uncertainty:
Δ: p<0.01
* : p<0.05
+: p<0.10

^{o}C decade^{-1}

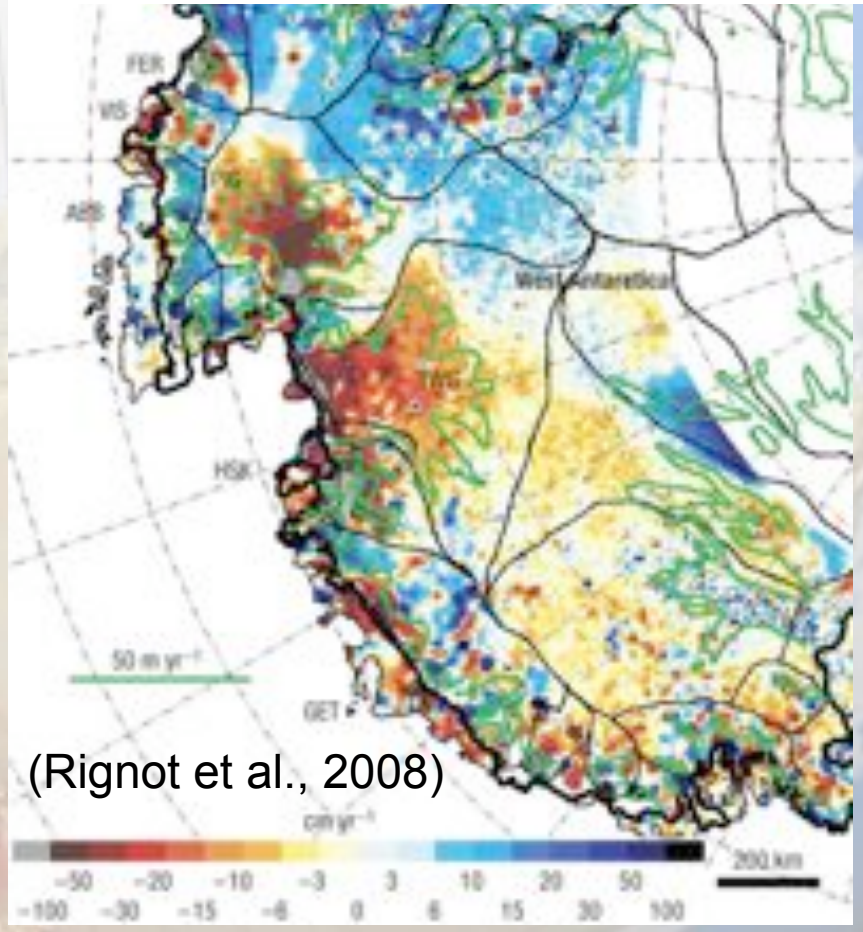
A. Monaghan, NCAR

Are warming trends explained by ice sheet thinning?

Change in skin temperature



Change in ice sheet elevation



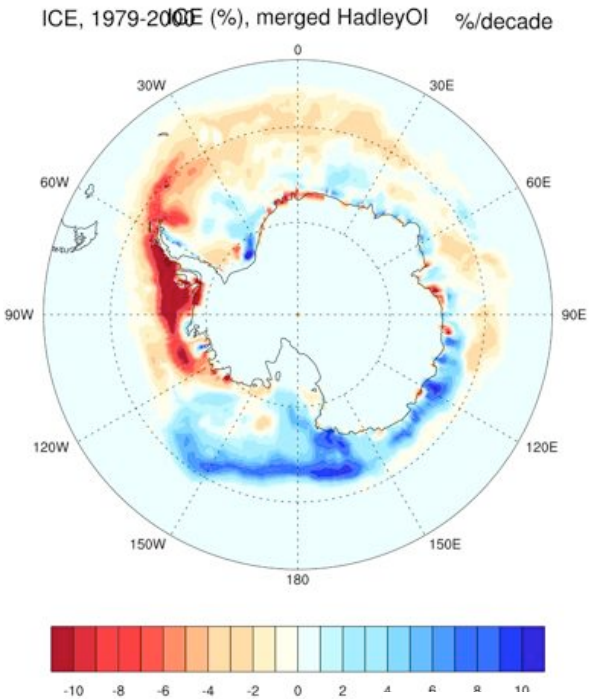
(Rignot et al., 2008)

5 m of thinning in 50 years is about 0.035°C warming

25 m of thinning in 50 years is about 0.17°C warming

An emerging Antarctic hot spot?

Change in sea ice concentration

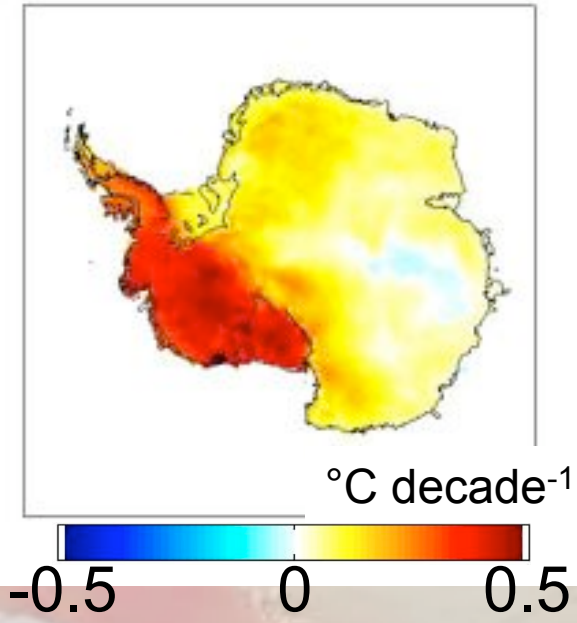


Less ice

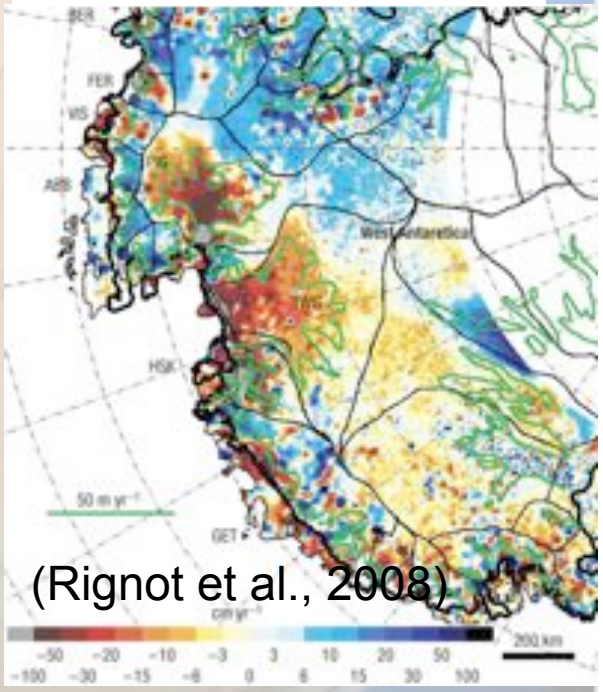
More ice

data from Hurrell, 2008

Change in surface temperature



Change in surface elevation



(Rignot et al., 2008)

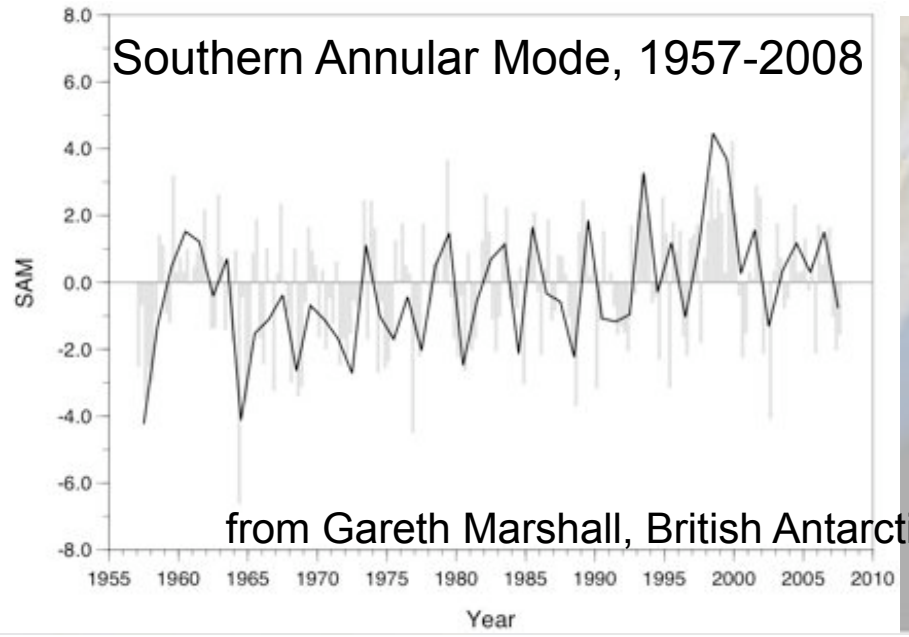
Is it all explained by the wind?

(as suggested by Overland et al (2008), Thompson and Solomon (2002), and others)

The Southern Annular Mode (SAM):

- Measures the strength of the meridional pressure gradient from 40°S-65°S
- A positive SAM implies a stronger gradient and stronger westerlies around Antarctica

- Had a strong positive trend from 1970s to early 2000s
- In, models, SAM trend is simulated in association with ozone depletion and increasing greenhouse gas concentrations



Is it all explained by the wind?

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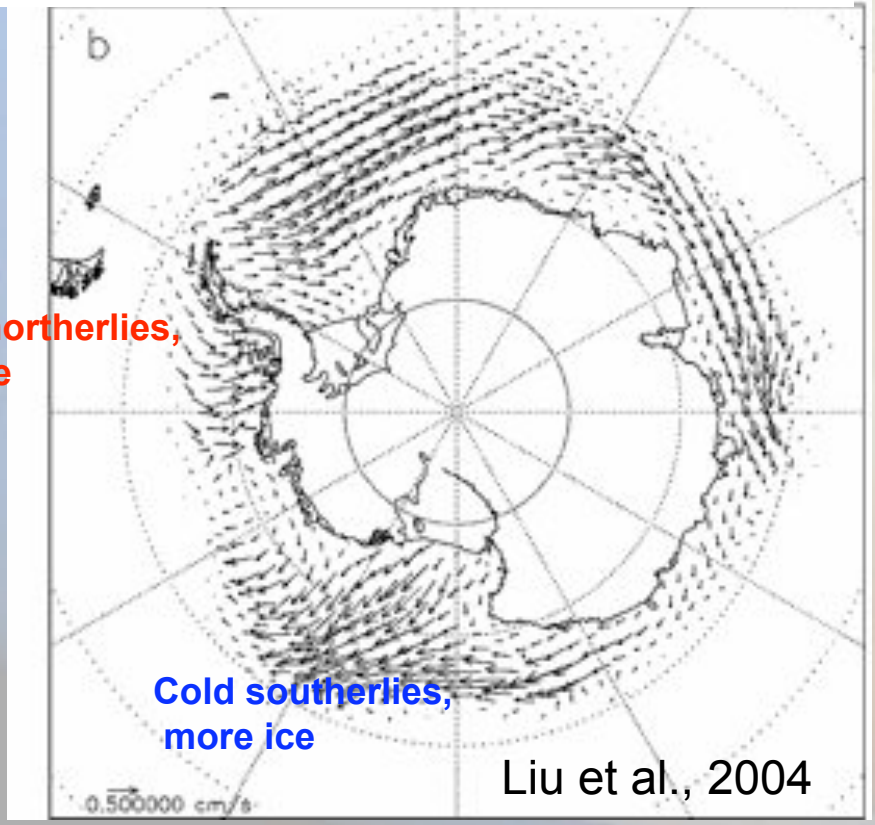
Ice drift anomalies regressed onto SAM

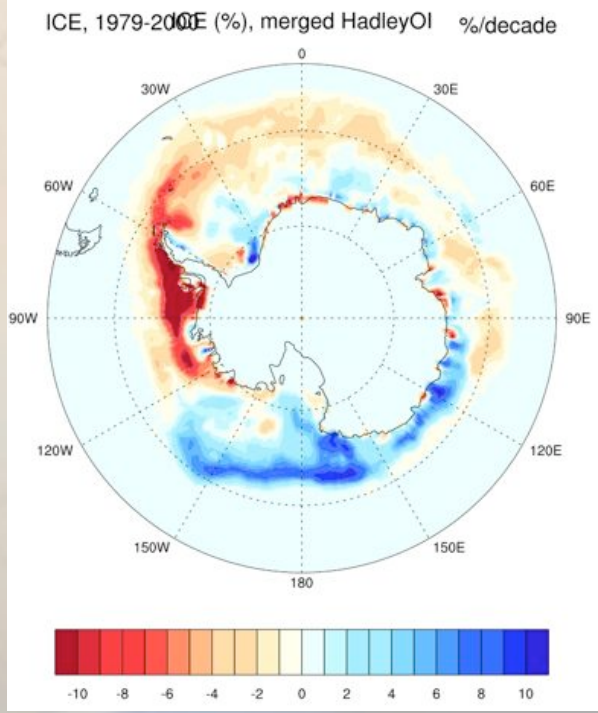


Warm northerlies, less ice

Cold southerlies, more ice

Liu et al., 2004

Change in sea ice concentration



Is it all explained by the wind?

(as suggested by Overland et al (2008), Thompson and Solomon (2002), and others)

Schneider et al. (2006); Schneider and Steig (2008): Antarctic temperature on timescale > 20 yrs is correlated with hemispheric mean temperature and SST, not with wind or SAM trend.

Steig et al., 2009: Pattern of warming trends cannot be directly explained by the increase in the strength of the zonal westerlies. The trend pattern is suggestive of the atmospheric zonal wave-3 pattern, yet the long-term trend is difficult to explain without including greenhouse gasses in model simulations.

Rignot et al. (2008): ice sheet thinning may be occurring because the ice sheet is feeling warmer ocean waters brought to the surface by increasing westerlies.

Liu et al. (2004): The pattern of trends in sea ice concentration looks like the wind trend, but the magnitude cannot be explained by the trends in atmospheric circulation alone.

1) Introduction
2) Back 200 years
   Schneider et al. 2006, *GRL*
3) West Antarctica, 20th Century
   Schneider and Steig 2008, *PNAS*
4) The last 50 years in detail
   Steig, Schneider et al. 2009, *Nature*
5) **What models say**
   in progress; work with Clara Deser, NCAR

Modeling studies

What are the relative roles of direct radiative forcing and observed changes in SST and sea ice in driving recent Antarctic temperature trends?

Modeling studies

Community Atmosphere Model (CAM) ensembles run by the CCSM Climate Variability Working Group (Deser and Phillips, 2008):

- **'SST + ATM'** forced by observed evolution of SSTs, sea ice concentrations, and atmospheric radiative forcing

- **'SST, ice'** with observed evolution of SSTs, sea ice concentrations. Radiative forcings fixed at 1990 levels

- **'ATM'** with observed evolution of radiative forcing and climatological SSTs and sea ice concentrations

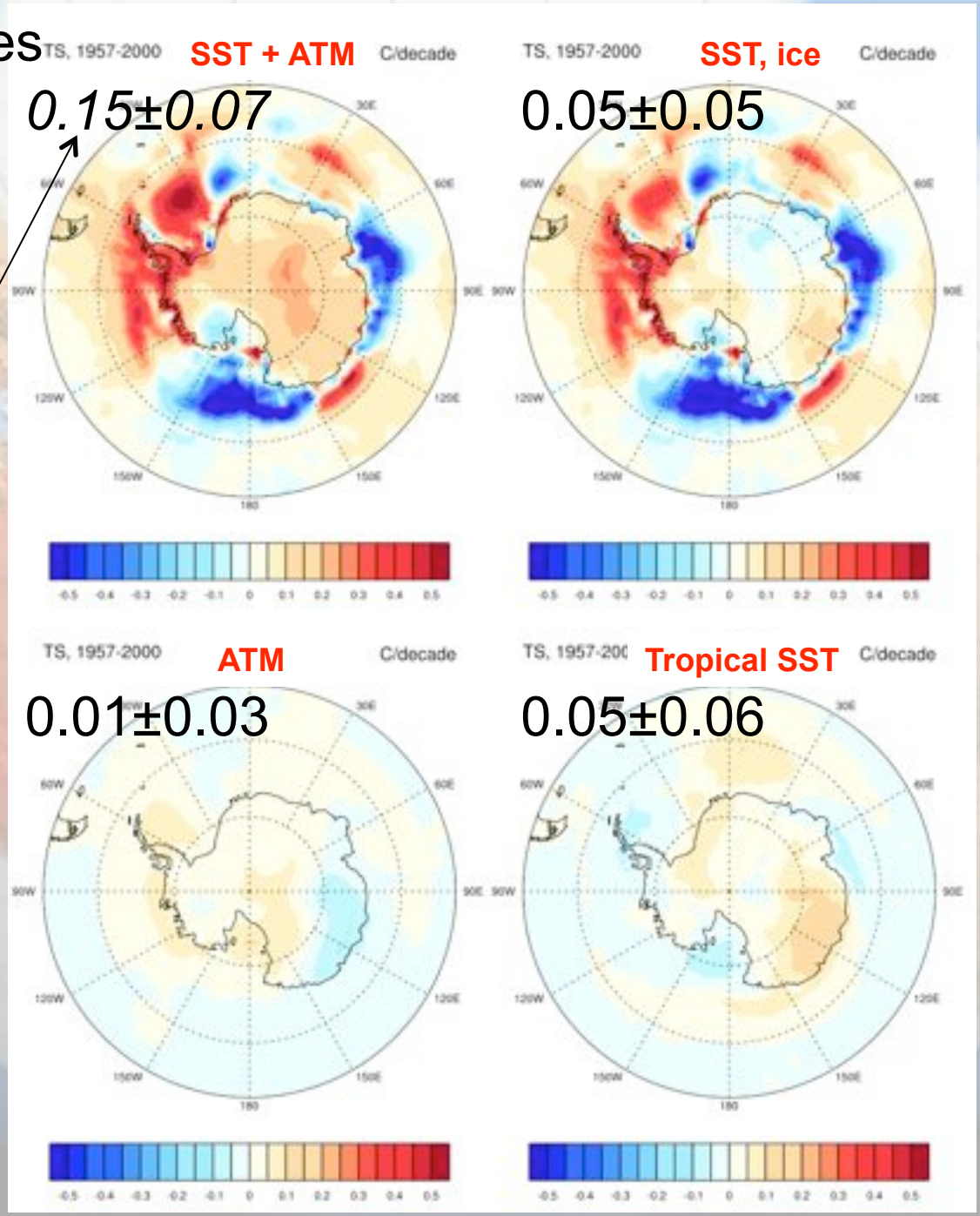
- **'Tropical SST'** with observed evolution of tropical SSTs, fixed radiative forcing, climatological extratropical SSTs and sea ice.

- And CCSM3 'Climate of the 20th-Century' integration with the fully coupled model. Same atmospheric radiative forcing as 'ATM' ensemble in CAM.

CAM ensembles
1957-2000

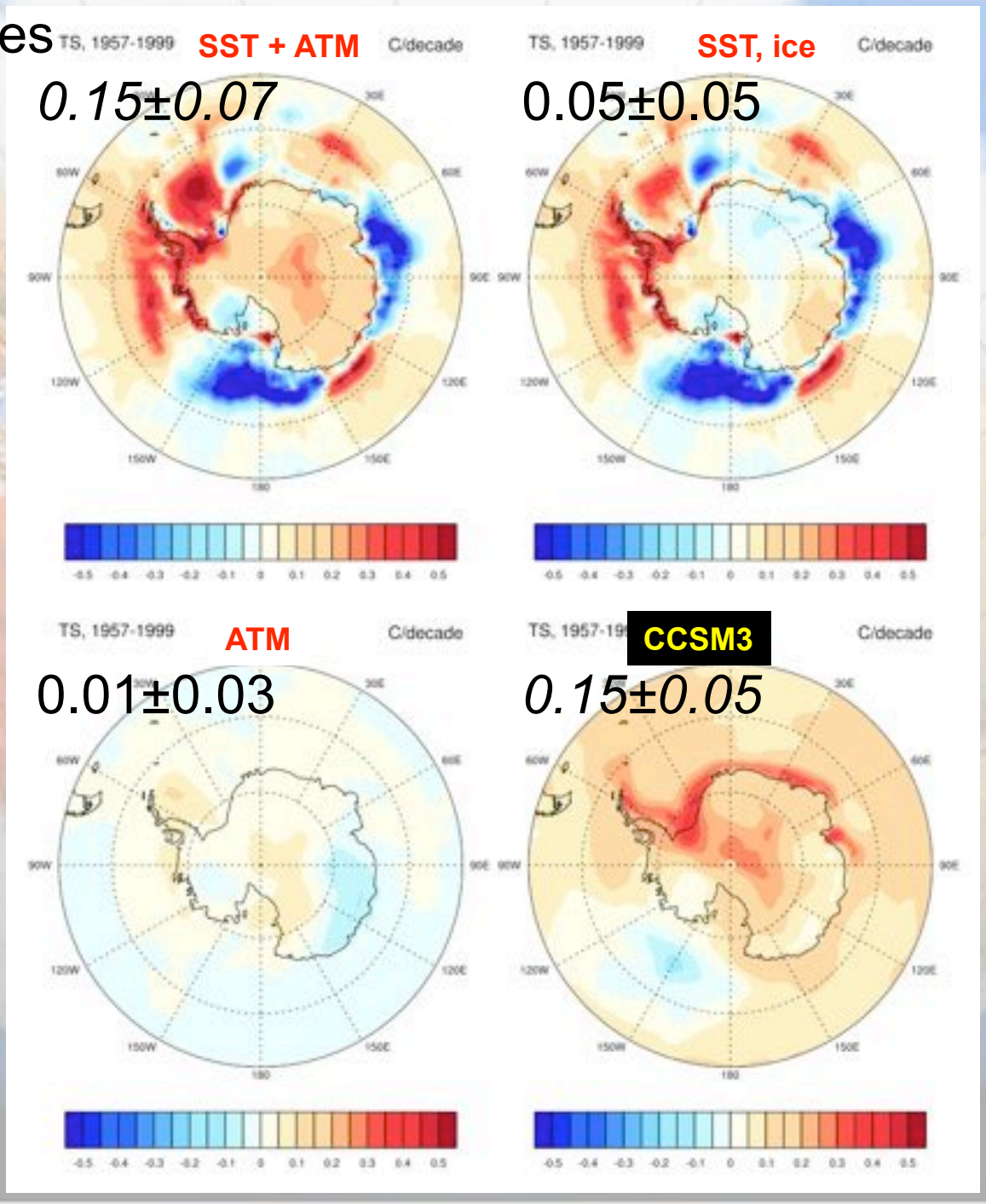
Annual trends
°C decade^{-1}

Continent average



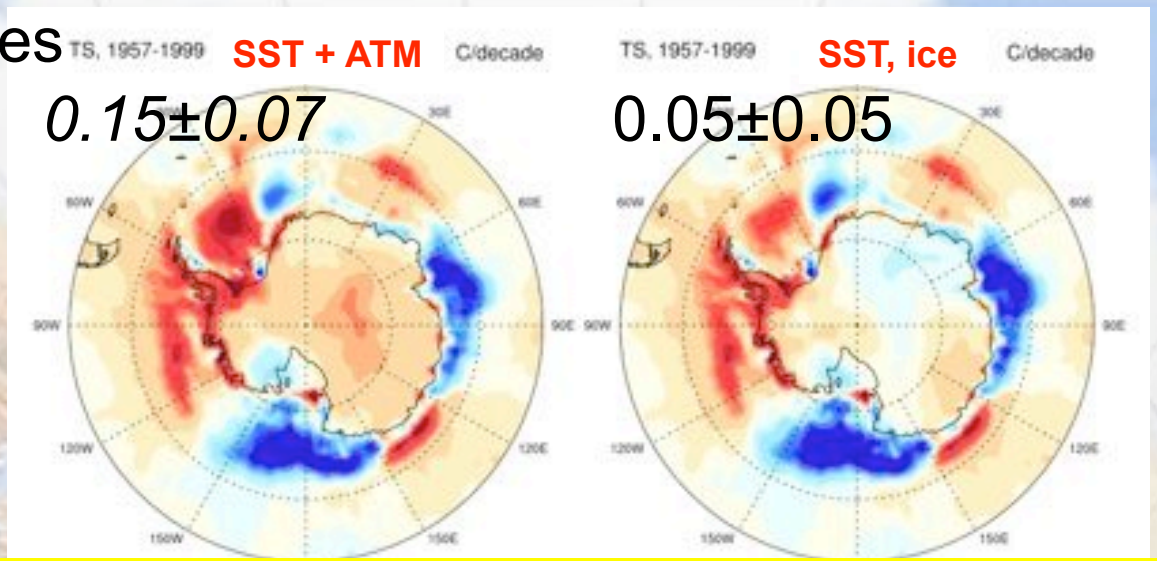
CAM ensembles
1957-2000

Annual trends
°C decade^{-1}

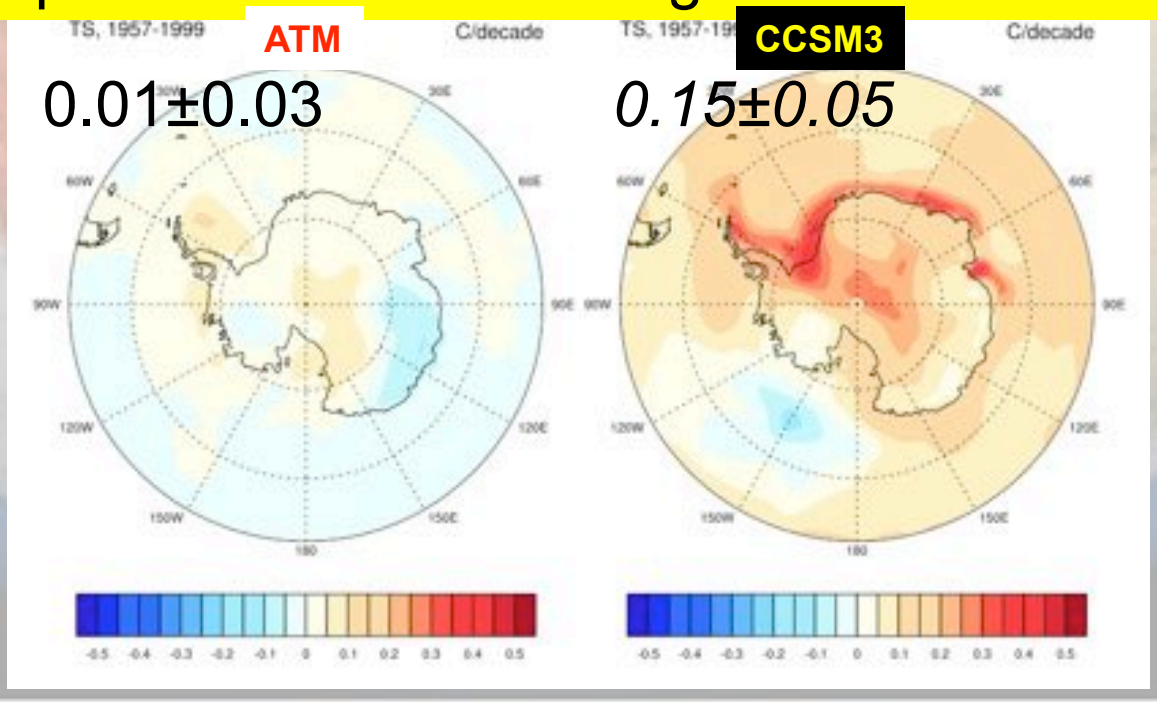


CAM ensembles
1957-2000

Annual trends
°C decade^{-1}

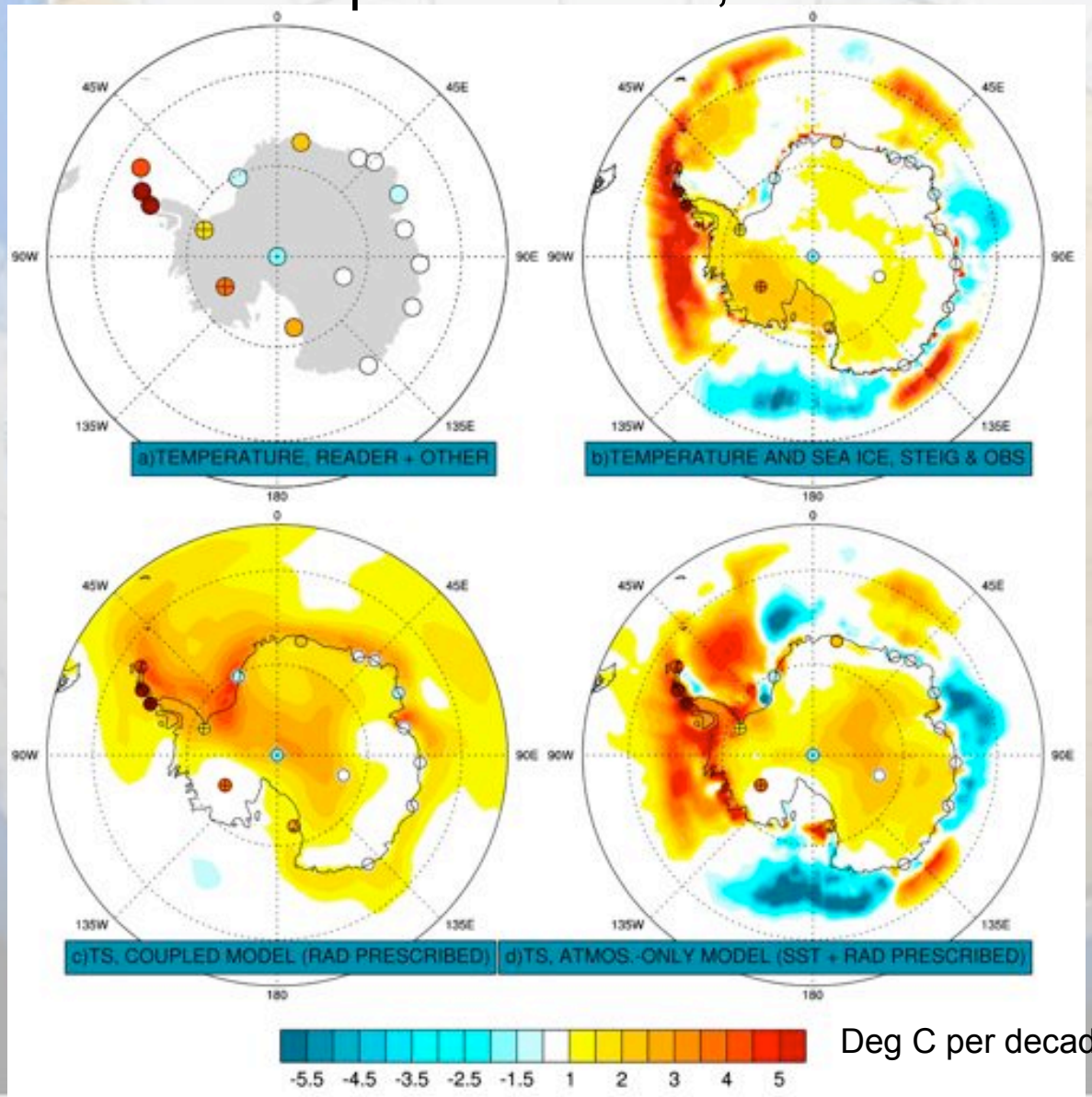


Direct radiative forcing (O_3, CO_2, etc) is required, but not sufficient to explain observed warming.



Observations compared with the NCAR CCSM3 and CAM

Annual temperature trend, 1960-2000

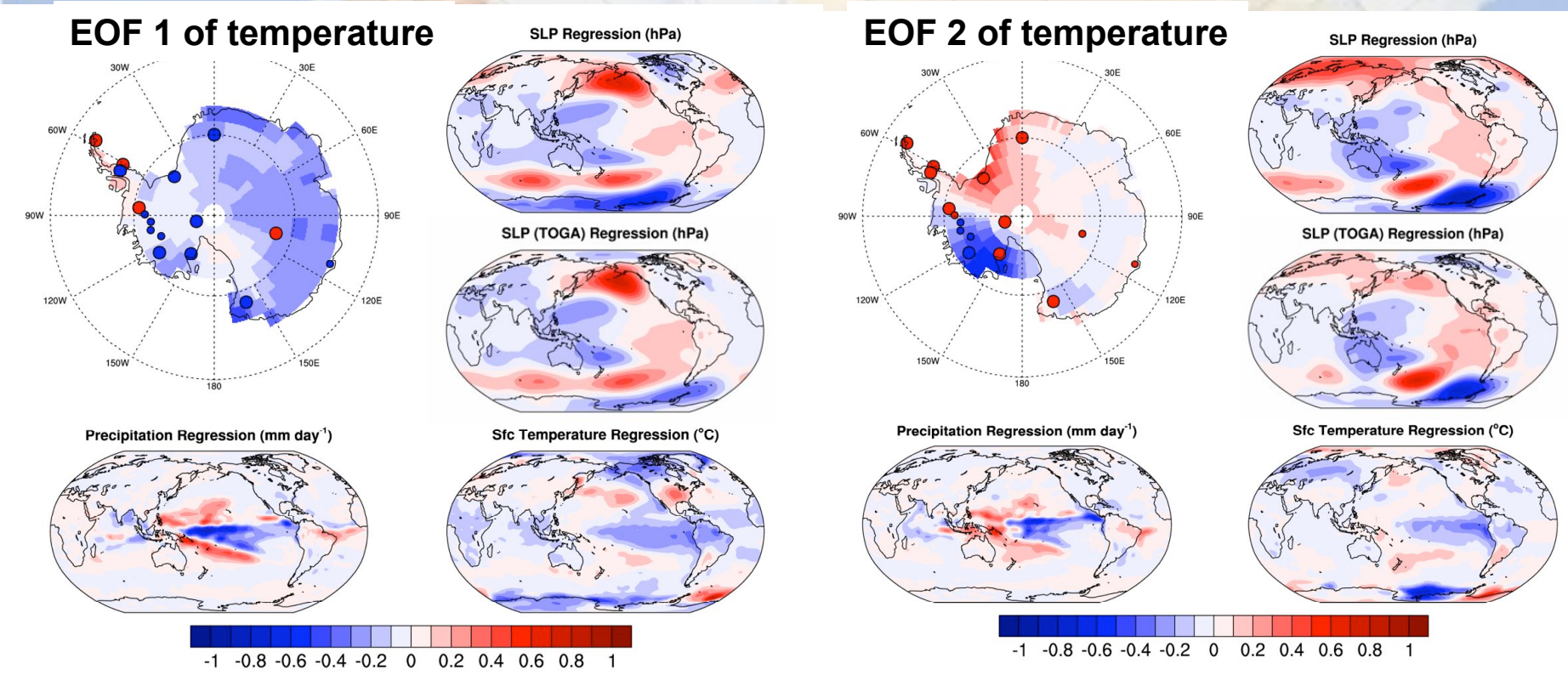


OBS

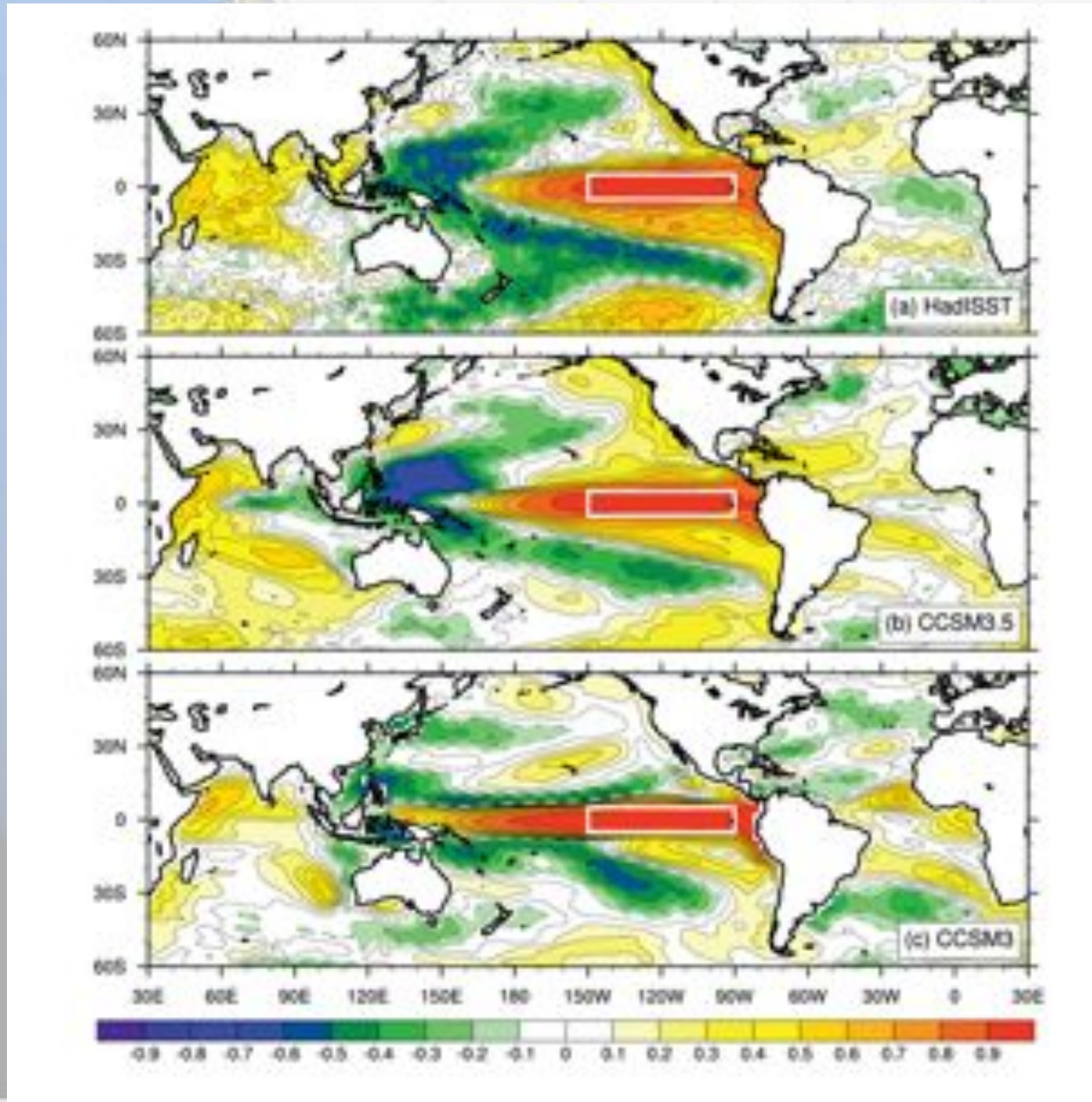
MODELS

Is the ‘tropical-Antarctic hypothesis,’ suggested by the 1940s ice core data, supported by models?

Results from CAM ‘SST + ATM’ ensemble

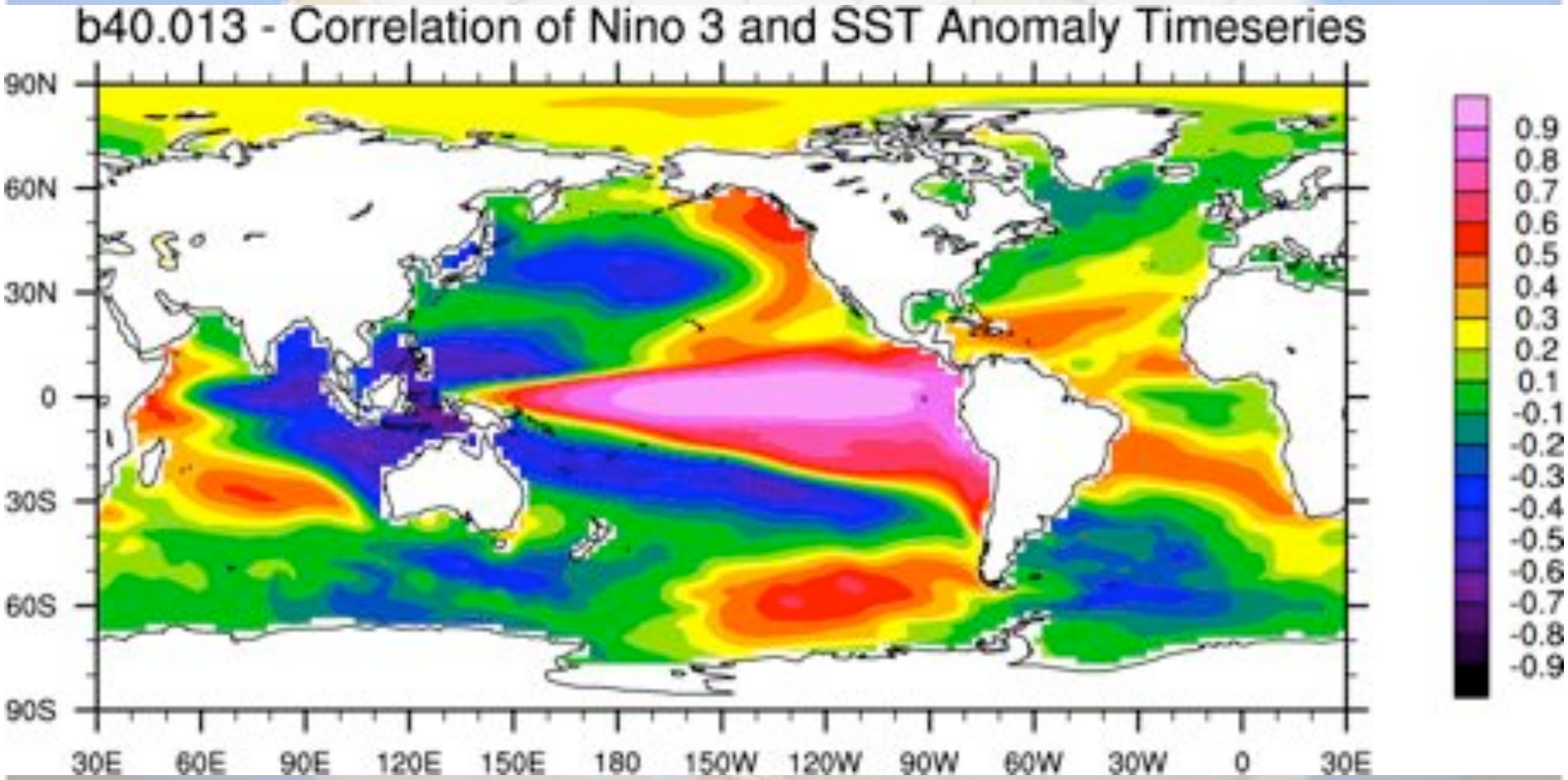


Improvements to models



Based on Neale et al., 2008

Peek at CCSM4



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   in progress
6) **Summary**

Summary

Back 200 years

Antarctic ice cores preserve excellent and detailed climate histories. Antarctica warmed a little during the past ~150 years; Interannual-decadal variations are large

West Antarctica, 20th Century

West Antarctica warmed more than East Antarctica; pronounced warm period in 1940s linked to tropical influence

The last 50 years in detail

Warming extends beyond the Peninsula region; Warming has already occurred, more than offsetting slight cooling.

What models say

Annual-mean trends are close to observed; both changes in radiative forcing (inc. ozone, CO_2) AND changes in SST, sea ice are required to explain observed trends


The END